SYSTEMATIC PROCEDURES FOR PLANNING RESEARCH

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ABSTRACT

This publication presents a generalized research planning system that applies to any level of planning from a bench scientist to a large research organization. The rationale for the generalized system is given to provide appropriate perspective and credibility. In addition, specific procedures are suggested for executing the activities identified in the generalized system. Flow diagrams are extensively used to help illustrate the planning activities and to show how they become part of a single planning system. The suggested specific procedures vary depending on the size of the research area to be planned and who does the planning. In most instances, the concepts of <u>what</u> should be done are emphasized leaving the <u>how to</u> and <u>who</u> variable. Finally an example is given of planning research in an area.

KEYWORDS: Experimental design, experimental procedures, experiments, planning research, research planning system.

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PREFACE

Two widely differing points of view generally surface when discussing research planning. The first is that research scientists are so isolated in their laboratories that they are not in touch with the real world, are only interested in their next publication so as to advance their careers (publish or perish), and though brilliant scientifically they don't have enough commonsense to come in out of the rain. Ergo if science is to truly benefit mankind, the efforts of research scientists must be coordinated and controlled so that duplication and counterproductive or irrelevant studies are at least minimized if not eliminated. Thus a formal planning mechanism is needed. The other viewpoint is that the essence of successful research is creativity and creativity cannot be legislated or dictated. Creativity is a rare gift to individual persons. To maximize its use in research, research scientists must be free to follow their creative ideas even if they seem somewhat outlandish or impractical. Prior to conducting research no one is sure what will be learned; after all, research is closely akin to discovery. Ergo the best planning system is to hire the most creative research scientists possible and let them do their thing. In other words, no formal planning mechanism is needed.

Strong arguments supported by numerous real life examples can be made for both points of view. Thus we must conclude that some truth exists for each and the issue is not which is right but rather what is the proper place for each. This publication attempts to strike a balance between having free uninhibited research scientists following their individual instincts and judgments (no formal planning system) and having procedures whereby individual scientists, immediate supervisors, research administrators, and others interested in what should be researched can collectively make decisions (have a formal planning system).

In developing a suggested balance, no effort has been made to thoroughly review relevant literature. In fact, most of the information presented comes from discussions with research scientists, supervisors, and administrators supported by a limited review of literature. Much of the discussion took place in a series of seminars and workshops held in the late 1960's in the Agricultural Engineering Research Division of the Agricultural Research Service (ARS) (now part of the Science and Education Administration). Further discussion occurred through efforts of the research planning committee of the American Society of Agricultural Engineers and in a few seminars held in the early and mid-1970's in the Northeastern Region, ARS. Some of the thoughts presented here have had limited trials, but most are the results of reflections on the discussions and hence are suggestions.

In fact, the suggestions are probably more appropriately termed hypotheses. As such, they are yet to be modified, validated, or rejected. To the degree that they stimulate further discussion, analysis, and testing of procedures for planning research, this publication will serve a useful purpose.

As it evolved through various drafts, many reviewers raised the question of whether the primary audience was a research scientist or administrator. The answer is both since the intent is to suggest a balance between "control from the top" and "freedom at the bottom." The only way balance can be achieved is to have a planning system that is broad enough to encompass both goals and yet complete enough so that both are related in an explicit manner. This publication attempts to define what such a system should look like and how it might operate. Thus the reader is cautioned not to let the apparent conflict of the two goals distract from seeing the big picture wherein both goals are achieved.

CONTENTS

SYSTEMATIC PROCEDURES FOR PLANNING RESEARCH

By Glen E. Vanden Berg[1]

CHAPTER 1—THE RESEARCH PROCESS

Research can be defined as careful, systematic, persistent study and investigation in some field of knowledge. Another definition is research is systematic, critical, intensive investigation directed toward the development of new or fuller knowledge of the subject studied. Both definitions contain the concept of knowledge. The first suggests that an activity or process is involved. The second explicitly introduces the idea that research is the development of knowledge. Before planning mechanisms can be discussed, the research process must be reasonably well defined and understood. This chapter outlines the major issues included in defining the research process to provide a frame of reference for research planning procedures.

Defining Scientific Knowledge

The two definitions of research given here suggest two primary concerns. First, what is knowledge, particularly scientific knowledge? Second, how is knowledge developed, discovered, or acquired? The answers will provide the basis for defining the research process.

We begin by noting that knowledge, as a minimum, involves material objects (natural and manmade), senses (the human perception of objects as through sight, smell, or hearing), cause and effect (relationships between objects or events), and concepts or ideas (the mind) that may or may not be directly related to material objects or the senses. Just how knowledge is involved is not very clear. For example, the concept of kindly love is not related to a material object or anything sensed. Yet the concept exists and could be called knowledge. Material objects exist and hence could be knowledge. But how do we know when we really sense an object or if we sense it that we perceive its universal objective self? The color of an object can change with light or at least it is perceived to change. Thus how do we know what color the object really is? A rushing waterfall makes noise so we could claim that the sound of falling water is knowledge. But how about sound for a deaf person? Does sound exist when it is not heard? To illustrate even further, consider looking at a stick partially under water. It appears to be bent and we can explain why. Don't we know when looking at the stick, if we truly understand how the water surface bends light rays, that the stick is in fact straight even though we clearly see that it is bent? Do we know it is straight because we believe it or because it is straight? Many other examples can be given to illustrate the difficulty in unambiguously defining knowledge.

1/ Associate Regional Administrator, Northeastern Region, Beltsville Agricultural Research Center, Beltsville, Md. 20705.

The difficulty in defining knowledge can be somewhat reduced by distinguishing between scientific knowledge and all knowledge. Scientific knowledge may be thought of as a subset of all knowledge and if all knowledge is represented by a circle, scientific knowledge would be a smaller circle within the larger circle. Science is defined as systematized knowledge of nature and the real world. Systematized is a key word in that definition because it suggests an internal linkage, structure, or organization of knowledge as contrasted to isolated facts. Thus scientific knowledge can be defined as the knowledge accumulated by mankind about nature and the real world.

How Scientific Knowledge Is Developed

The definition of scientific knowledge sufficiently answers the first question about what is knowledge so that we can proceed to the second. A sufficient although incomplete answer can be obtained from epistemology, which is a branch of philosophy. Two points of view have evolved to explain how mankind acquires scientific knowledge when it is defined as given here.

The first point of view is the rationalist approach and involves deduction. Rationalists begin with the idea that the universe is a harmonious whole and that truth can be deduced from the clear mathematical and logical principles that govern the universe. Furthermore, knowledge does not come from the senses. If it did, universal objective knowledge would be impossible because empirical (observed) truths are accidental propositions and just something that happened. No assertion can be made that an event must always happen the same way. No matter how numerous the examples of an event may be, they do not prove that the event will necessarily always take place or occur in the same way. Thus true knowledge must consist of universal and necessary truths based on principles and what can be deduced from them. These principles come from the mind, and reason alone can decipher the mathematical logical order of the universe. Experience does not create knowledge; it only makes it explicit.

The second point of view is the empirical approach and involves induction. Empiricists argue that no such thing as innate, moral, or logical principles are present in the mind at birth. Indeed the mind does not have built-in preconceptions or information about nature and the world. Rather, it begins learning the simplest things first and builds up to complex matters from elementary forms of knowledge (inductive reasoning). Thus the truth of specific propositions is recognized before general propositions are accepted; in fact, many general propositions are not recognized until attention is drawn to them and then only if the observer is trained by previous education to be able to understand them. Thus knowledge is acquired <u>only</u> through the accumulation of sense impressions (data); it is not derived by the mind from innate truths already present in the mind.

Today both viewpoints have elements that appear to "make sense" but also elements that don't make sense. No acceptable reconciliation has been made that provides a basis for a happy compromise. The two viewpoints do, however, provide a perspective for describing the research process because two approaches are suggested for developing new knowledge. The difference in approaches is (1) the specific processes used to discover or learn the new knowledge and (2) how it is validated--accepted by others as new, universal, and objective. Rationalism accepts that new knowledge exists when it has been <u>logically</u> <u>deduced</u> from basic principles or laws. Mathematical derivations are examples of deductive reasoning. Validation rests pri-

marily on the logic of the deduction in the rationalist approach. On the other hand, in the empirical approach, validation rests on the acquisition (perception) of objective universal data from the real world. The scientific method using hypotheses and experiments is an example of a good data acquisition technique. The accuracy, objectivity, and universality of the acquired data, not any logic involved, become the critical factors for validating new knowledge in the empirical approach.

Although the two approaches exist, seldom is rationalist-developed knowledge accepted today just on the basis of logic alone. For example, Einstein's theory of special relativity was eventually confirmed by the Michelson-Morley experiments, which were conducted between the mountain peaks in California. However, his just as rational general theory of relativity has not been confirmed. It has been conceived but not perceived. An accepted modification in the rationalist approach is to develop the new knowledge by deductive principles and then obtain real world data from a representative situation but independent of that used in the deduction and compare the deduced knowledge with the observed event. When agreement is satisfactory, the new knowledge is accepted as valid. However, the new knowledge was generated from the deduction, not the observed data. The modified rationalist approach is an accepted method of research today and is most clearly illustrated in computerized modeling of complex systems. The model is built on known facts and logical assumptions (deduction) and then tested by comparing predictions from the model with independent real world data obtained from the situation that was simulated by the model.

A Generalized Research Process

The empirical approach can be subdivided into six basic steps. They are (1) defining the problem, (2) planning the experiments, (3) carrying out the experiments, (4) analyzing the results, (5) interpreting the results, and (6) reporting the results. In these steps, an experiment has the meaning associated with the scientific method, which is acquiring data to disprove a hypothesis. An experiment thus is a carefully prescribed data acquisition plan that enables comparison within the data so as to make a valid conclusion. An experiment always involves the concept of subjecting one or more variables to a prescribed treatment and then comparing the treated variables with the non-treated (often called control) variable. In such a situation the effect of the treatment is learned. If the experiment was properly designed, its construct then permits valid interpretation of the disproof of the proposed hypothesis that was the basis for the experiment.

On the other hand, comparison in the modified rationalist approach has a distinctly different meaning from experiment. Here the comparison is direct between the hypothesis/deduction and data. Furthermore, seldom is any degree of control exercised in the data acquisition plan. For example, the amount or kind of fertilizer applied, temperature at which a process is held, or length of treatment that is experimentally manipulated while the appropriate measurements are made illustrates the exercise of control. Lack of control refers to not attempting to manipulate any variable but simply measuring the appropriate variables so as to define or assess the situation. Data acquired in such a manner are fully adequate to permit direct comparison between a hypothesis/deduction and the data, but no comparison can be made within the data. Thus the word test rather than experiment probably better describes the direct-comparison no-need-for-control situation.

Control or treatment associated with experiments is not necessarily quantitative. In fact, experiments of a qualitative nature have probably made greater contributions to knowledge than quantitative ones. Qualitative treatment or control enables conducting the what-would-happen-if-experiments, and they can lead to basic principles. Numbers can be determined later to add the quantitative dimension. Control and treatment are closely related in the context of conducting experiments, but they are not necessarily synonymous. The important distinction, however, is that one or both must be present in an experiment. Neither is necessary in a test.

The distinction between experiment and test as defined here is important because of the mental approach required for planning. The critical aspects of planning an experiment are deciding what variables should be held constant or treated and then what the treatment should be. When these decisions are made, what to measure is almost self-evident. On the other hand, the critical aspects of planning a test are deciding what to measure so the situation or event is adequately described. The thought process thus is greatly different. Although the distinction between an experiment and test can be clearly made conceptually, the distinctions can become small in the real world. For example, determining the rate of growth of chickens for certain diets under certain environmental conditions would constitute a test if the results were to be compared with a hypothesis that predicted the rate of growth. On the other hand, the same measurements would be involved in an experiment where the rate of growth was being determined for different diets. In this latter instance, the planned control over the diets (the treatment) and comparison of growth between diets make it an experiment. Obviously the distinction is a fine point and small. Just as obviously other situations exist where the distinction between an experiment and test is large.

Recognition of the conceptual distinction between an experiment and a test enables applying the same six basic steps to the modified rationalist approach as apply to the empirical approach if the word experiment is replaced with the word test. However, the apparent similarity is somewhat misleading. For example, a considerable difference exists in the defining problem step. In the empirical approach, that step can be subdivided into (1) reviewing or observing the problem part of the real world, (2) formulating and/or revising a mental model of the real world, (3) proposing multiple hypotheses, (4) proposing experiments to disprove the hypotheses, and (5) selecting the best experiment. For the modified rationalist approach, the subdivision is (1) reviewing or observing the problem part of the real world, (2) formulating and/or revising a mental model of the real world, (3) identifying the basic principles or laws involved in the mental model, (4) analyzing or applying the principles and laws to the mental model, and (5) relating the conclusions of the analysis to the mental model. Steps 3-5 are the development of the new knowledge, and the process would stop if the rationalist approach were being followed. But in the modified rationalist approach, the new knowledge must be validated by a test. In the empirical approach, steps 3-5 merely result in a data acquisition plan, and the observation of that data is the development of the new knowledge. Thus the underlying philosophy and the specific activities involved in the problem definition step of the two approaches are very different.

Fully understanding the differences in the two approaches is critical for developing a generalized research process. In the empirical approach, the proposal of hypotheses and experiments is sometimes described as intellectual inventions. Either can

result from a creative flash of insight that the human mind can accomplish almost instantaneously. Thus the key steps of 3 and 4 in the empirical approach can occur in an instant, with the mind functioning at a highly creative level. On the other hand, steps 3-5 in the modified rationalist approach can require many hours of effort as new knowledge is deduced. A mathematical derivation is one example. A systematic mental application of "what would happen if" so as to develop the logic of a situation is another example. Executing such activities does not preclude flashes of insight from occurring to advance or enhance the analysis process, but they occur in a different context than the intellectual inventions of the empirical approach. Thus the differences between the two approaches can be great.

However, just as the conceptual distinction between an experiment and test can become small, so can the distinction between the empirical and modified rationalist approach of the problem definition step. For example, nothing prevents using the rationalist approach to develop hypotheses in lieu of an intellectual invention. Or, nothing prevents a person following the rationalist approach from leaping to a conclusion (hypothesis) without going through all the logical steps required by the deduction approach. In either situation a hypothesis results that leads to proposing experiments. On the other hand, experiments cannot always be proposed (often because the element of control is not possible) so that a test is used to validate the hypothesis. In other words, even though the empirical and modified rationalist approaches are distinctly different processes, they represent only two of a multitude. Numerous combinations of the two are possible and often the distinction is more degree than kind. Thus a range of activities often can occur and a generalized research process will have to take the range into account.

The similarity between the empirical approach and modified rationalist approach permits defining the generalized research process. In keeping with the concepts previously discussed, the generalized research process involves the following six sequential steps:

1. Define the problem -- activities include (a) observing the real world through a qualitative "seeing of the situation" and/or a thorough review of relevant knowledge, (b) analyzing the observations and available knowledge to produce hypotheses or deductions about the situation (the analysis can range from an intellectual invention to a logical deduction based on existing principles or laws), and (c) proposing experiments or tests to validate or reject the hypotheses/deductions.

2. Plan experiments or tests -- activities involve translating the conceptual experiment or test into some plan that can be carried out wherein data will be acquired.

3. Carry out the experiment or test -- activities can range from obtaining data in the available literature to qualitative observations of selected material, such as with the aid of a microscope to using computer-controlled apparatus for programing the variation of a variable while simultaneously measuring all pertinent variables.

4. Analyze results -- activities involve manipulating the data so that the results can be more easily understood and interpreted and can range from tabular or graphic organization of the results to sophisticated statistical or mathematical treatment.

5. Interpret results -- activities involve synthesizing the results into a whole or relating them to available knowledge and/or practical applications for some utilitarian purpose.

6. Report results -- activities are self-evident but often two distinct audiences are involved, each requiring a different report. The first audience is science at large and the second is the immediate users of the knowledge. In the case of applied research, the two audiences often are different.

One final point should be made about the generalized research process. Planning is involved only in the first two steps. The last four are execution. The research scientists and their technicians are the most logical persons to plan step 2. But even most of the planning in step 1 can best be done by research scientists. Thus if a research planning mechanism is to be developed that will permit a balance between control from the top and freedom at the bottom, it will have to occur in the first step.

CHAPTER 2—A GENERALIZED RESEARCH PLANNING PROCESS

Another definition of research is that it is a two-step process, where first a carefully structured question is asked and second the precise methods of science are used to answer the question. In this definition the precise methods of science include both an experiment and a test as they are defined in chapter 1. Thus the two-step process definition includes the empirical approach, the modified rationalist approach, or any combination of the two--the generalized research process. The two-step process definition permits better focusing on research planning since planning in the two-step process is deciding what question to try to answer and then how to answer it.

Linking the Precise Methods of Science to Questions

To develop a generalized research planning process based on the two-step definition, we need to relate the precise methods of science to answering questions. When that relationship has been established, the planning aspects can be isolated without losing an overall one-system perspective.

The scientific method is probably the most discussed precise method of science, it is widely used in research, and it avoids the inefficiency of trial and error procedures. This method involves (1) proposing multiple hypotheses, (2) proposing critical experiments to disprove the hypotheses, (3) carrying out the experiments to get clean results, and (4) recycling. The method is based on the principle that the fastest way to accumulate knowledge is to proceed by negatives and end in affirmatives after exclusion has been exhausted. It is also based on the principle that no such thing as proof in science exists since some later alternative explanation may be just as good or even better than a current explanation. (Note that this argument also counters the rationalist premise that perceived knowledge is accidental and hence cannot be universal.) Therefore science advances by proposing alternative hypotheses, attempting to disprove them since only one experiment is needed to disprove, and adopting the hypothesis that cannot be disproved.

The concept of disproof is difficult because it requires a scientist to first propose something and then try to demonstrate that the proposal is wrong and thereby the scientist appears softheaded. On the other hand, a scientist appears to be disputatious when defending a single hypothesis as being correct. Proposing multiple hypotheses avoids these difficulties, since the "pride of authorship" of a scientist proposing one hypothesis is minimized. The technique is an accepted part of the modern procedures of the scientific method.

Although the scientific method is a powerful research tool, it does not give any guidance on how to make a hypothesis. As discussed in chapter 1, a hypothesis that results during the first step of the general research process may result from a creative flash of insight (an instantaneous intellectual invention), a careful and logical deduction that may have taken many hours of effort, or something in between. If the hypothesis resulted from the rationalist approach, how did the scientist decide what area to analyze? If the hypothesis was of the

instantaneous insight kind, what triggered it? Did the scientist decide that today is the day to generate a hypothesis and so shuts the office door, sits back, and by noon emerges with a hypothesis? Or, did the scientist get hit on the head with an apple as allegedly happened to Sir Isaac Newton? But even more disconcerting, after a hypothesis has been made, what justification exists for expending time and resources on disproving the hypothesis? Or, if the modified rationalist approach is being used, what justification exists for expending time and resources on conducting tests to validate the hypothesis? In other words, is the new knowledge really needed; or, is new knowledge in some other area of more importance? This last question is of particular concern when research resources are limited.

The concerns raised by these questions can be eliminated if (1) a need for establishing new knowledge can be demonstrated and (2) a link between that knowledge and the activities identified in the generalized research process discussed in chapter 1 can be established. To that end, we begin by stating an obvious fact, a question that cannot be answered identifies unknown knowledge. If answering that question can be shown to be of value (such as help solve a problem or fill a critical gap in knowledge), justification exists to try to answer the question.

We proceed by recognizing that a proposed answer to a question is a hypothesis. In fact, several plausible answers to a single question may result from a thorough analysis of the situation so that multiple hypotheses can be proposed. For the modified rationalist approach, the question directs the analysis to the area to be analyzed. Although the deduced hypothesis may be more from perspiration than inspiration, nevertheless the fact that it is a proposed answer to a question is true until it has been validated. In the empirical approach, the proposed answer is often more of an intellectual invention and thus in the empirical approach the resulting hypothesis may be more from inspiration than perspiration. Regardless of how a hypothesis is made, however, it is a proposed answer to a question.

When the scientific method is being used, the proposal of experiments to disprove hypotheses provides the link between identified knowledge that needs to be developed and activities in the generalized research process to develop that knowledge. It directly relates the data to be acquired to an established need for that knowledge. In the pure rationalist approach, recall that the deduction would not be a hypothesis but would be accepted if the logic could not be faulted. In the modified rationalist approach, the new knowledge is considered a hypothesis that needs to be validated. Thus both the empirical and the modified rationalist approaches require data acquisition before the knowledge is accepted as valid.

In completing the linkage we need to recognize that not all questions are best answered by hypotheses. If a question asks how much something is happening (such as reduction in yield, losses in storage, or incidence of occurrence), proposing a hypothesis does little to help design a data acquisition plan. The hypothesis is reduced to a guess about the size of the numbers. Even if the modified rationalist approach is used and it leads to the prediction of the numbers, they must still be validated by a test. In fact, when a test as defined in chapter 1 is used, it is always trying to answer the general question, "What really happens in the real world?" and a hypothesis is not an acceptable answer. Thus when a hypothesis becomes trivial or does not fully answer a question, a better procedure is to directly measure the how much or what is really happening rather than proposing a hypothesis. When that procedure is

followed, the question might better be termed a measurement question. Thus some questions can be designated hypothesis and some measurement.

With the recognition of two types of questions, we can complete the linkage between questions and activities in the generalized research process discussed in chapter 1. Four linkage pathways exist. First, if the nature of the question is clearly measurement, no hypothesis should be proposed and the question itself will direct a data acquisition plan whether it be an experiment or a test. Second, if the question is clearly hypothesis, the nature of the question will direct the analysis efforts to propose hypotheses regardless of whether the empirical or rationalist approach is used. Third, if the scientific method is followed, the hypothesis will direct experiments that will in turn direct a data acquisition plan. Finally, if the modified rationalist approach is followed, the test to validate the new knowledge will direct a data acquisition plan. Thus linkages exist for the major combinations of research processes and these linkages will also cover any variations within the major types of processes.

One final point should be made about planning experiments and tests as they are defined in chapter 1. The conceptual approach for planning an experiment when the scientific method is used is to disprove a hypothesis by demonstrating that the specific event or situation does not occur that way. Nothing is implied in that concept that requires programed manipulation of key variables so a treatment effect can be determined. In fact, a test as defined in chapter 1 can prove that an event doesn't happen just as well as an experiment. That can happen because a test has de facto control since a test must represent a specific situation and not a random occurrence. The thrust of a test in the modified rationalist approach is to prove a hypothesis by establishing that the hypothesized event or situation does occur in the real world. The proof rests in the judgment that the predicted situation is close enough to the real situation so as to be useful for some purpose. Although control or manipulation of a key variable is not necessary in a test, neither is it precluded. Thus a test can contain the key elements that normally distinguish it from an experiment and can be used to disprove a hypothesis in some special situations.

The distinct yet subtle differences between tests and experiments and their role in a complete research process are critical to a bench scientist when planning and executing a precise method of science. On the other hand, these differences and roles are inconsequential when a research administrator is planning for coordination. In fact, considering the differences would likely only confuse and complicate the task. Thus for the remainder of this publication, the word experiment is defined as the acquisition of data in the research process regardless of how it is accomplished. Planning experiments thus will be developing a data acquisition plan and the word experiment is being broadened in concept to include all the precise methods of science.

Criteria for a Generalized Research Planning Process

With a broader definition of experiment and a two-step definition of research, we can concentrate on isolating the planning aspects of research. Deciding what question to try to answer may be thought of as planning in an area. Deciding how to try to answer the question may be thought of as planning experiments, where experiment includes all the precise methods of science. A systematic process for making these decisions has certain requirements that may be termed criteria for a generalized research

planning process. We will proceed to develop a generalized planning process by identifying the necessary criteria.

When selecting a question for answering, relevance must be considered because seldom can we afford to do research today on something simply because it is interesting. Relevance is complicated because big and little questions can be asked that can lead to big and little hypotheses being proposed. Big broad hypotheses, however, have limited usefulness. When too broad, they are so general that they hypothesize nothing. Furthermore, resources may be limited so that the required experiments cannot be carried out--the hypothesis cannot be validated. Similarly, a broad measurement question may not be answerable because required resources are not available. Consequently, a hierarchy of questions usually will be necessary in order to show relevance to an objective and yet have some small sharp questions that can be researched within experimental limitations.

A hierarchy of questions can be visualized as a research question tree. The trunk of the tree is analogous to a research objective. The various branches of the tree represent major subdivisions of the objective. The twigs on the branches represent the small, sharp questions that can be handled within experimental limitations. An essential requirement for a research planning process is to develop a hierarchy of questions that need answering.

Usually not enough resources are available to answer all the questions identified in a hierarchy. Consequently, priorities must be established before selecting a question. When establishing priorities, the researchability of a question should be considered. Science at large is constantly making progress. What is not researchable today may be easily researchable tomorrow. Thus the second requirement for a research planning process is establishing priorities.

After priorities have been established, key critical researchable questions will be identified and available resources can be allocated to them, or budget requests for new resources can be made. Allocation considerations should include funds, the scientific expertise of the scientists involved, and the research facilities available to them. Allocation of available resources including requests for new resources is therefore the third requirement for a research planning process.

After the assignment of high priority questions to scientists and the allocation of resources, scientists can use scientific methods to plan within the constraints of available resources. Using scientific methods to plan experiments thus is a fourth requirement for a research planning process.

At the conclusion of an experiment, the results should be evaluated and incorporated into the selection of the next question to be answered. In fact, evaluation makes the research process iterative and causes constant recycling; it is a key part in the research planning process and is the fifth requirement for a research planning process.

These five requirements for a generalized research planning process are illustrated in figure 1. Symbols are used to designate activities, decisions, and time. A rectangle represents an activity to be done, an elongated diamond a decision, an oval a completed activity, and lines and arrows represent time. The time lines in figure 1 represent the sequence in which the activities should be completed, not how long an activity may require.

The generalized process in figure 1 can be understood best by recognizing the two types of research planning discussed earlier. The first type is planning research in an area. Activities 1-4 and 6-8 in figure 1 are directly related to planning research in

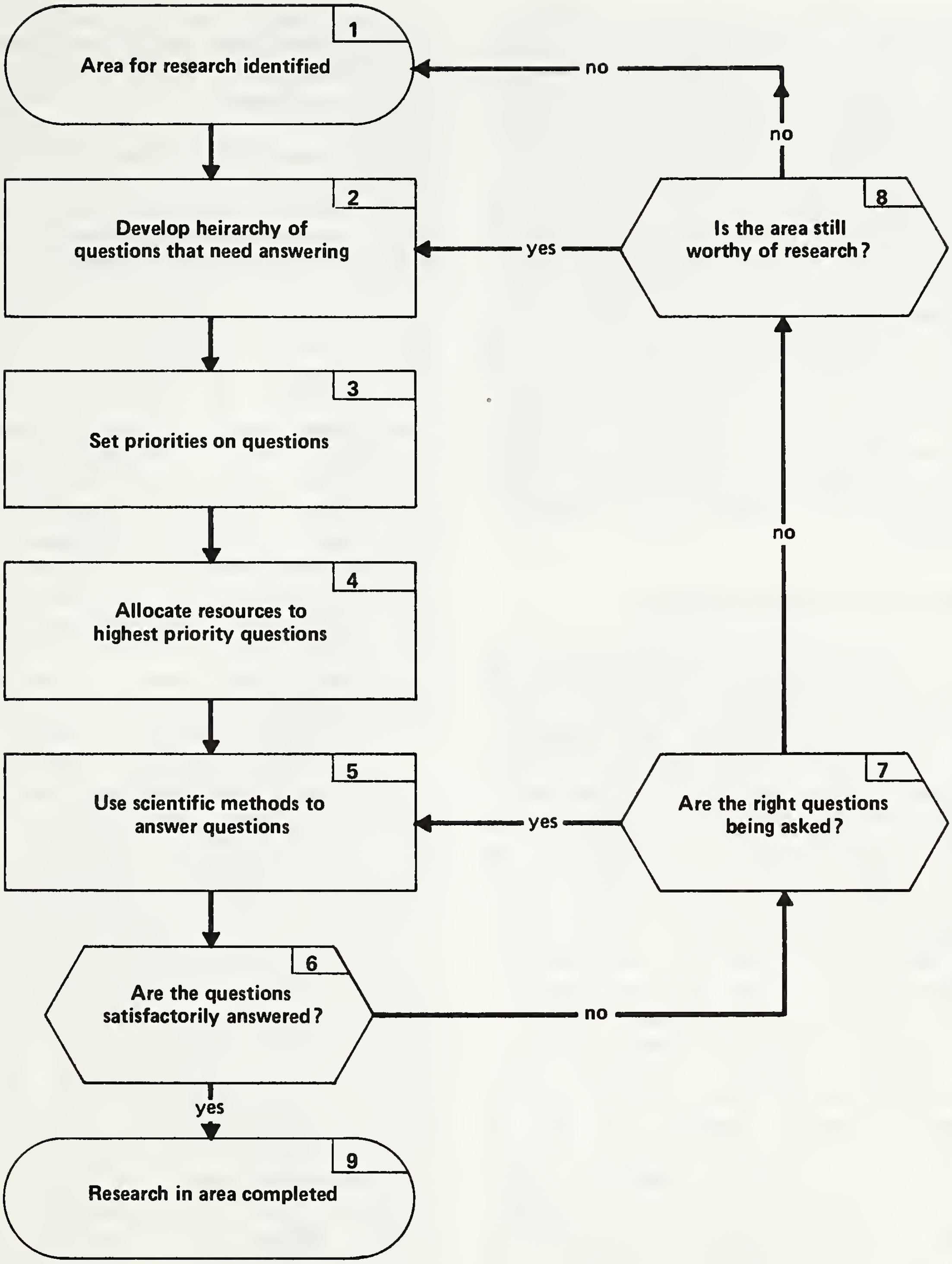

Figure 1.--Generalized research planning process.

an area. The second type is planning experiments. The first part of activity 5 is directly related to planning experiments and constitutes that done by a scientist and/or technician in steps 1 and 2 in the generalized research process discussed in chapter 1. The other steps of the generalized process (3-6) are also part of activity 5 but are not planning activities. The generalized planning process in figure 1 shows how both planning in an area and planning experiments must be part of one systematic process if the planning is to be most effective. That requirement originates because the results of a completed experiment can and often do significantly alter the scientific course that should be followed.

What, How, and Who Systems

The activities identified in figure 1 indicate what should be done to successfully complete planning. Nothing is indicated about who should do the planning and how the who should proceed. Thus before a system can be fully defined, the who and the how as well as the what must be defined. How can be defined by subdividing an activity into smaller activities, which in essence define another what system. The new what system in turn then requires defining its who and how systems before it is fully defined.

To illustrate the what, how, and who system concept, consider three situations where the generalized research planning process can be applied. The first and simplest is when one or two scientists identify an area. For example, the lack of methodology to test a hypothesis might trigger additional research planning. The scientists would need to develop a hierarchy of questions, set priorities, allocate resources, and plan specific experiments to establish the needed methodology. The hierarchy of questions probably would be small. Setting priorities and allocating resources likely would primarily involve allocating the amount of time the scientists would devote to the methodology questions. In all likelihood, they could execute the activities quickly and informally, possibly only documenting their final conclusions. Thus the who would be the two scientists and the how would be the informal discussion with limited documentation.

A second situation exists when a small group of scientists, possibly from several different disciplines, are involved or concerned with an identified area. The hierarchy of questions likely will be larger, the disciplines may have interests that bias their opinions on priorities, or they could represent different organizations and thereby complicate the resource allocation. Thus the how system likely will require more formal procedures than for the first situation described here. Furthermore, considerable documentation may be necessary to keep everyone informed.

A third situation is when a large complex area is identified and a large number of people are required to carry out the planning because of the breadth of expertise required. Undoubtedly research managers would be involved and they would be naive if they did all the planning through activity 4 without involvement of some of the scientists who will be responsible for executing activity 5. Furthermore, who knows better than research scientists what is known or what is researchable in light of the state of the art of science at large. On the other hand, can even research managers (let alone research scientists) remain truly objective when setting priorities? Probably nonresearch groups should be involved when setting priorities in large complex areas of research. Therefore for this situation, the who is not obvious but will involve a number of diverse people and certainly the how will involve formalized structured procedures if

the diverse who's are going to fully understand what they are doing.

Thus several different procedures could and should be used for each activity in the generalized research planning process. The procedures should vary depending on the situation (usually related to size of area) that affects the who and how parts of the system. Systematic procedures will be suggested in the next three chapters by subdividing each activity into new what systems and thereby defining how the generalized system should be done. Emphasis on the subsystems will be on what should be done with some discussion of the how and who parts in order to clarify the what. Modifying the proposed procedures or developing new ones and validating both are tasks yet to be done before a fully developed and accepted generalized planning process will exist.

CHAPTER 3—PLANNING IN AN AREA

Planning in an area has two parts. The first is covered in activities 1-4 in figure 1, which are discussed here in sequence. They precede the planning and execution of experiments. Evaluation is the second part of planning in an area and will be discussed in a separate chapter.

Identifying an Area

The generalized research planning process illustrated in figure 1 begins with a completed activity--identification of an area for planning research--because identification can occur in many ways, such as a result of a crisis, recognition of new opportunities, or possibly the need to reevaluate an existing program. Waiting for a crisis to arise, the recognition of new opportunities to occur, or the need to reevaluate an existing program to emerge seem to be haphazard ways to identify an area. Thus two specific procedures will be discussed that help identify areas in a more orderly manner and simultaneously tend to keep the areas small and manageable.

The first procedure is to establish a hierarchy of goals. The concept of goals is perhaps most clearly stated in the procedures associated with management by objectives. A hierarchy of goals could be either those that a research organization uses or they could be specific goals established for a particular subject of research. For example, in 1978 the U.S. Department of Agriculture had 12 of 247 lowest level elements in its program structure that identify areas of agricultural research.

A second procedure was basically followed at the Working Congress on Research to Meet U.S. and World Food Needs held in Kansas City, Mo., on July 9-11, 1975; it is illustrated in figure 2. (The numerical identification of the activities in figure 2 all begin with the number 1 to indicate that they are subdivisions of activity 1 in figure 1; this practice is followed for all figures in this publication.) The process is particularly useful (1) where the subject area is very broad and (2) in situations that cut across numerous research organizations involved in the area. The five activities in the process (activities 1.2 - 1.6) are self-explanatory in terms of what should be accomplished. How each is accomplished and by whom can be highly variable. For example, at the World Food Conference, its organizers executed activity 1.2 and used it as a basis to identify participants. The remaining activities were then executed by the participants in a conference setting. Other techniques are possible. For example, all or parts of the activities could be done by correspondence. A sequence of conferences could be held rather than one. Regardless of how the five activities are executed, the process in figure 2 does provide an orderly means for reviewing a broad area of research and breaking it down into a limited number of high priority narrower areas where additional research planning should be concentrated. The underlying philosophy of the approach is that extensive research planning efforts should be concentrated on a limited number of critical areas.

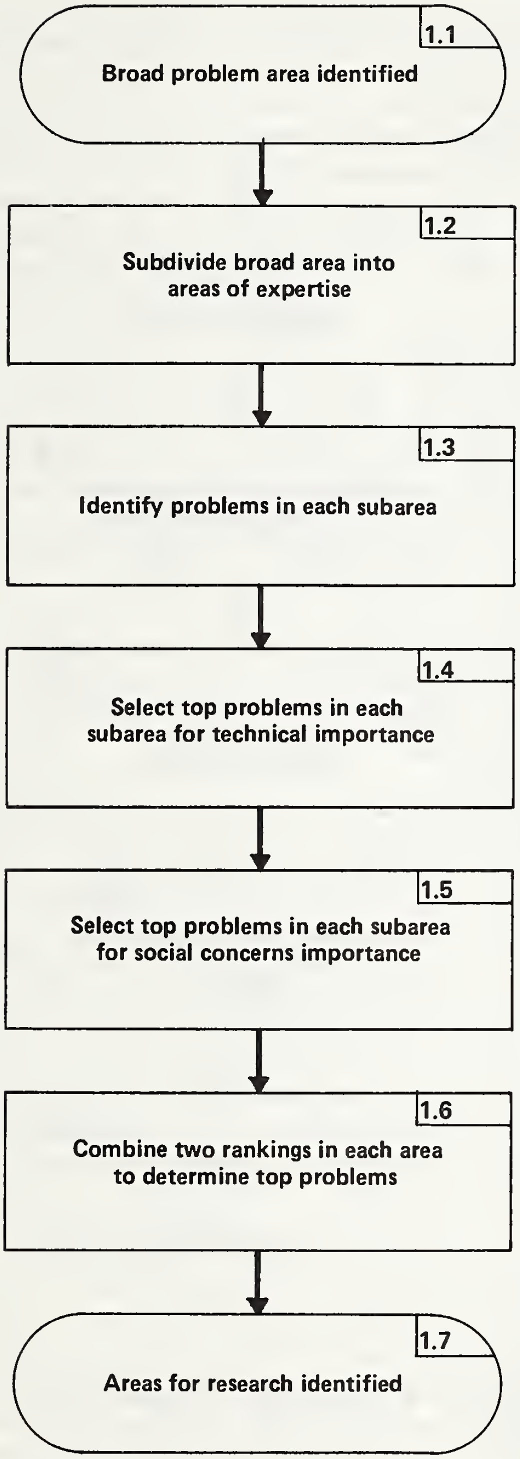

Figure 2.--Systematic process for identifying a research area.

A Systematic Process for Developing a Hierarchy of Questions

A specific process for executing activity 2 of figure 1 and doing intensive planning in an area is shown in figure 3. (Note that each activity in the figure has an identification number beginning with 2 to indicate it is a subdivision of activity 2 in figure 1.) The process is based on the general concepts of three levels of planning: (1) Identifying goals by developing a scenario, (2) strategic planning to determine alternatives, and (3) tactical planning within the strategies. Each type of planning is different yet all three are linked to make a whole. The general concepts of these three levels of planning are incorporated in the specific process shown in figure 3.

The process begins when research planning is initiated after an area has been identified. The first activity is to write a single sentence that states the problem to be studied as shown in activity 2.2 of figure 3. If more than one problem exists, a statement for each should be developed. A single sentence problem statement begins to further define an area. The statement should imply objectives that are desired but cannot be achieved because of the problem. The statement also should explicitly indicate why the objectives cannot be achieved. Writing a problem sentence is demanding and not easily accomplished unless the problem and its relation to the identified area are clearly understood. To illustrate, an objective may be to grow corn. However, poor germination, excessive pests, or harvesting losses could be problems that would prevent achieving high corn yields. A single sentence stating the problem can be a major step in identifying and defining the area of consid-

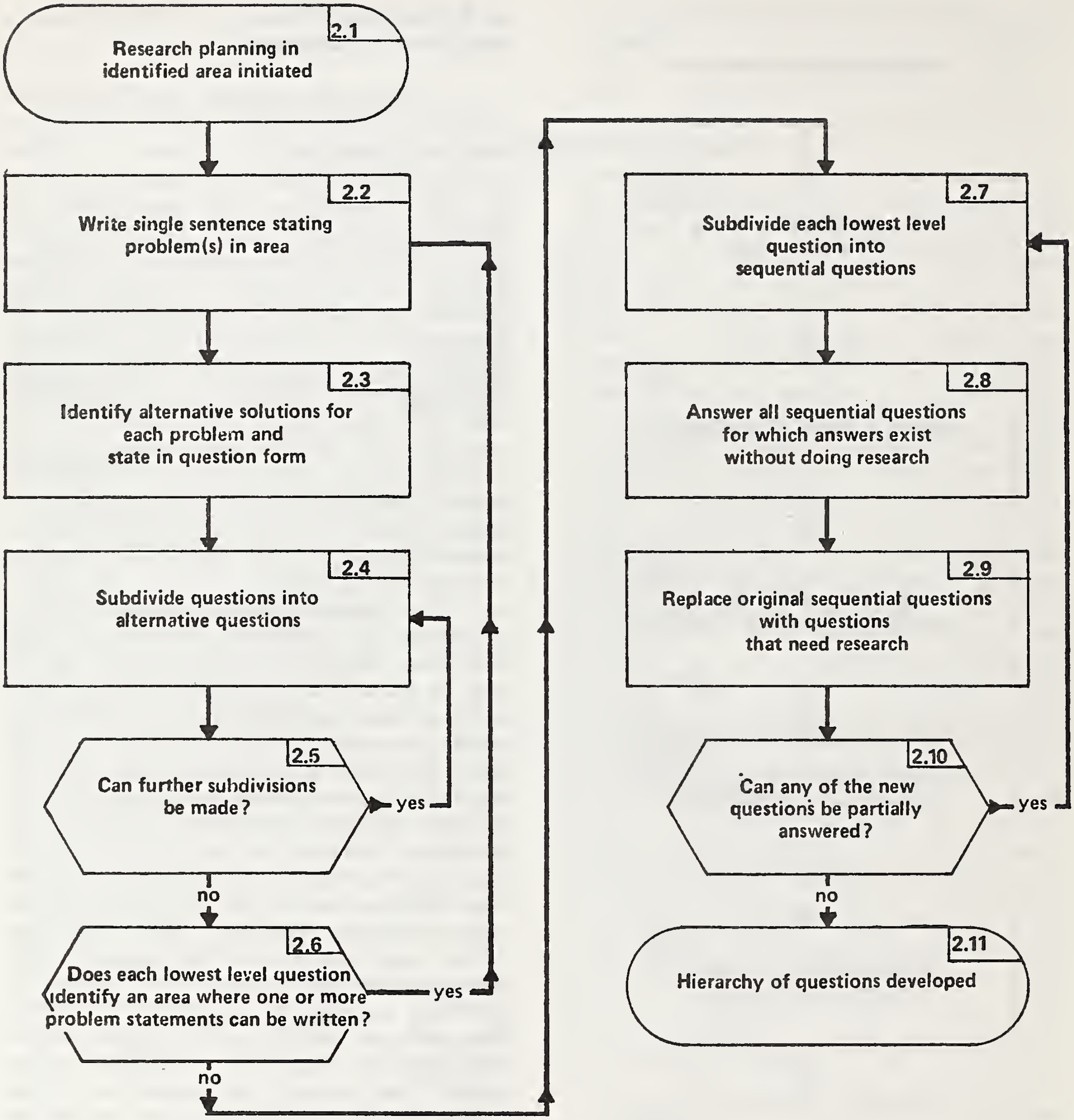

Figure 3.--Systematic process for developing a hierarchy of questions.

eration because it is equivalent to writing a <u>scenario</u> in the three-level approach to planning discussed here.

Both the desired objective and the problem that is blocking achieving the objective are necessary in order to carry out activity 2.3 in figure 3. The activities in 2.3-2.5 in figure 3 are equivalent to <u>strategic planning</u> as discussed here. Alternative ways of achieving the objective are potential solutions to the problem and they are independent. For example, insect control might be achieved by plant re-

sistance, chemical control of the insect population, or biological control of the insect population. Each way is independent since doing one does not require doing either of the others. Usually only a limited number of alternative ways exist to accomplish an objective, but careful thinking is required to make sure all the potential solutions are identified.

Alternative ways are not necessarily mutually exclusive. Identifying mutually exclusive ways of achieving an objective may not always be possible, but independent ways always can be identified. Mutually exclusive alternatives can be visualized like different routes on a road map. Each route will fully accomplish the goal of getting from "a" to "b," but only one route at a time can be followed. On the other hand, independent ways can be visualized like the major components of an automobile. Suppose the objective is to increase gasoline mileage by 50 percent. This objective might be achieved by (1) improving engine performance, transmission, or both or (2) decreasing friction losses of the rolling wheels, wind losses associated with the body shape, or both. The engine, transmission, wheels, and body all can be modified yet none has to be modified just because one of the others was. Furthermore, selecting one component for modification does not preclude selecting any other; thus they are not mutually exclusive but they are independent.

The concept of mutually exclusive ways as defined here implies ways wherein each will fully accomplish an objective and selecting one excludes selection of any other. On the other hand, independent ways imply ways that may only partially accomplish the objective and generally several or all of them may be simultaneously selected. A special situation is possible where alternative ways exist that can fully accomplish the objective yet each can be selected. For example, complete insect control is possible with plant resistance, chemical treatment, or biological methods. Yet if each method is only partially successful, all three can be used. This special situation is not mutually exclusive but is more than just independent. It might appropriately be termed a fully independent way. In a like manner, independent ways that have only the potential to partially accomplish an objective might appropriately be termed partially independent ways. For example, completely eliminating wheel and wind friction probably would not permit increasing gasoline mileage of an automobile by 50 percent.

The distinction between the three types of alternative ways is important because when identifying alternative ways, progress can be made most rapidly by first trying to think of mutually exclusive ways, then fully independent ways, and finally partially independent ways. The distinctions also help to assure that alternative ways are independent and not just subdivisions of a whole.

The concept of the three types of alternative ways is also helpful in carrying out activity 2.4. Each solution question identified in activity 2.3 implies an objective. When subdividing the question, division first into mutually exclusive, then fully independent, and finally partially independent ways to accomplish the objective implied by the question is the simplest way to make the subdivision. Decision activity 2.5 in figure 3 simply extends activity 2.4 to the point where questions can no longer be subdivided into alternative ways to accomplish an implied objective. Activities 2.3-2.5 develop the major limbs and branches of a research question tree and complete strategic planning.

Decision activity 2.6 is a checkpoint that causes recycling when necessary to compensate for initially starting with a large complex area of research. It in essence creates more but smaller research question trees.

Thus it modifies the procedure so that in a loose sense activities 2.2-2.6 could be used as a third method to identify an area for planning research.

Activities 2.7-2.10 in figure 3 are equivalent to <u>tactical planning</u> as discussed previously. Activity 2.7 begins the effort to identify twigs on the branches of a research question tree. Sequential questions are distinctly different from the three types of alternative questions defined previously. Sequential questions are dependent on each other. Furthermore, they usually must be answered in a consecutive order. They are major subdivisions of a whole but are not alternatives nor are they independent. The answer to the last sequential question should fully answer the broader question. A standard example of sequential questions is: What methods are now used, what is wrong with them, how can they be improved, what other methods are feasible, and which method is best? Here the word method is defined as a way to accomplish an implied objective expressed in the broader question that needs answering. Activity 2.8 is self-explanatory. The intent, obviously, is to eliminate from the research question tree the knowledge that is already known. Activity 2.9 is carried out by examining the answers to the original sequential questions. The answers usually will suggest new questions that are more specific than the first sequence of questions. Decision activity 2.10 recycles the process so that only questions that cannot be answered remain; when a "no" decision is made, the hierarchy of questions is fully developed. When the hierarchy contains more than one subdivision, the sequence must be applied to each lowest level question until a no decision is made in order to fully develop the hierarchy.

The activities and decisions in figure 3 identify what should be done to develop a hierarchy of questions. Much of the preceding discussion covered how the activities could be done but nothing was implied about who should execute each activity. The three general situations discussed at the end of chapter 2 provide a basis for identifying who. The first is when one or two scientists identify an area. In this situation, probably they should execute all activities (2.2-2.10) in figure 3. To the degree they might need assistance in activity 2.8, they could obtain it either by reviewing literature or consulting with other experts in the area.

The second situation envisions an area that would be considerably more complex than the first situation described here, but one where the required subject matter expertise to successfully execute activities 2.3-2.10 can be done by a small group of scientists. For example, if 5 to 10 first-level supervisors of research scientists could carry out activity 2.8, the area would fall in the situation envisioned. However, because of the complexity of the area, they likely would need to follow more formal procedures and document decisions more fully than in the first situation.

The third situation involves a large complex area where a large number of people are required to effectively execute activity 2.8 because of the breadth of expertise needed. For such situations, a much more structured approach is required. In general, complex areas can best be handled by having a small group such as a steering committee execute activities 2.2-2.6. The resulting lowest level questions can then be organized by areas of expertise and each area assigned to a different small group to execute activities 2.7-2.10. Although not necessary, it probably would be useful to have at least one member of the steering committee on each area-of-expertise committee to provide continuity and liaison.

Because of the number of persons likely to be involved in the third

general situation, and because most will have direct involvement with only part of the whole, those involved need to keep clearly in mind the immediate objective. That objective is to develop as simple a hierarchy of questions as possible, which, if answered, will solve the problems that have been identified. They should not be concerned with the practicality of answering the questions either from a theoretical researchability or available resources standpoint. Those concerns will be addressed when activities 3 and 4 are executed. The objective of activity 2 is to identify what could be done, not necessarily what should be done.

A Systematic Process for Setting Priorities

A specific process for executing activity 3 in figure 1 is shown in figure 4. The activities describe what should be done with no indications of how or who. To a large degree, the how is determined by the complexity of the original area. Thus if only one or two scientists are involved, they can easily and quickly execute all four activities (3.2-3.5). However, if the area is complex and falls within the third general situation described here, the how probably should be quite different. Certainly who executes each activity will be different.

To better illustrate the process, some alternative how's for the complex situation are discussed. Although activities 3.2-3.4 are indicated as separate activities, they need to be planned together. Identifying raters, for example, will depend on criteria selected, since raters will not make effective judgments if they don't believe they have personal knowledge on which to make the judgments. Thus selecting raters who will be effective is highly dependent on the criteria that are developed.

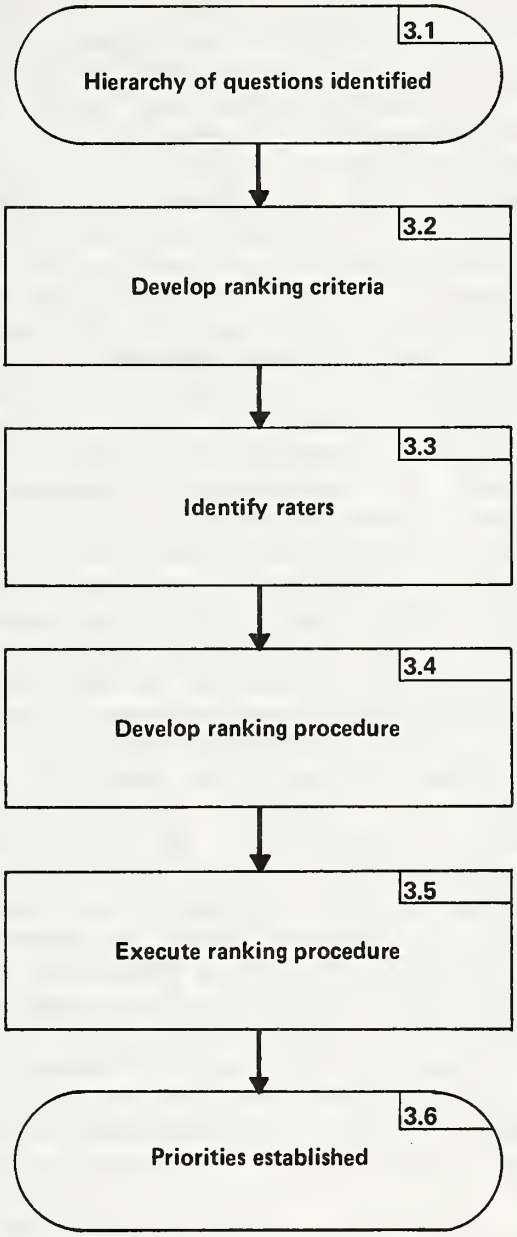

Figure 4.--Systematic process for setting priorities.

Many schemes have been used to establish criteria. They have ranged from an all-inclusive subjective single evaluation to elaborate weighted criteria that are explicitly written. In general, however, at least four issues should be addressed. The first is researchability. That issue is often addressed by stating the probability of success and usually requires

research scientists involved in related research to make the judgment. The second issue is the impact on science or technology--estimating potential worth of answering a question. If the immediate impact of answering a question will be on science, scientists representing a broad range of disciplines probably can best make the judgment. On the other hand, if the direct impact is on technology, possibly the users of the technology rather than scientists can better make the judgment. Since the impact of research doesn't always fall neatly into science or technology, identifying raters is not always easy. The third issue is impact on society, with particular attention to potentially adverse effects and could be appropriately termed technology assessment. However, the procedures for an elaborate technology assessment are usually not justified for each question, but each question should be judged in some manner from a social concerns viewpoint. Raters for this criterion probably should include so-called environmentalists, consumers, and sociologists. The last issue is urgency, which involves both the importance and timeliness of completing the research. Probably the same raters that assess the impact on science or technology can also assess urgency. Whatever ranking criteria are developed, these four issues should somehow be included.

Once ranking criteria and raters have been identified, the exact procedure to be followed in 3.5 can be finalized. A working conference is one technique. Correspondence is another. Interviewing would be a third possibility. Regardless of the method of involvement of raters, how their judgments will be measured and combined must be established. In complex situations, usually the raters will need to assign numerical values and then these values combined in some logical manner to give the final priority. No criteria exist on how to combine ratings (such as arithmetic average, weighted average, or products) except that the system used should make sense. If all raters participate in a working conference, their participation in fine tuning the system is desirable. Regardless of the ranking procedure used, however, all concerned should remember that if numbers are used, they merely reflect the highly subjective judgments of people whose honest opinions will vary considerably. The numbers should not be interpreted as representing a degree of precision that does not actually exist. Thus some statistical evaluation of any numerical ranking procedures is desirable.

A Systematic Process for Allocating Resources

A specific process for executing activity 4 in figure 1 is shown in figure 5. As was true for activities 2 and 3, the execution of activity 4 is simple if only one or two scientists are involved. If the identified area is complex, however, execution will be more difficult. The process shown applies to the latter situation. Before elaborating on the process, the relationship between activities 3 and 4 in figure 1 should be discussed. Often the two activities become merged so they are not clearly distinguished. Their relationship is simple in that priorities are one of three factors that should be used by decisionmakers when allocating resources. These factors are (1) the priority of the research program, (2) the manpower, money, and facility requirements to complete the program, and (3) the availability of these resources. Program is used here to indicate a grouping of related researchable questions. Research managers strive to shift resources among programs in order to optimize the benefits from research undertaken within the limits of available resources. The process illustrated in figure 5 is

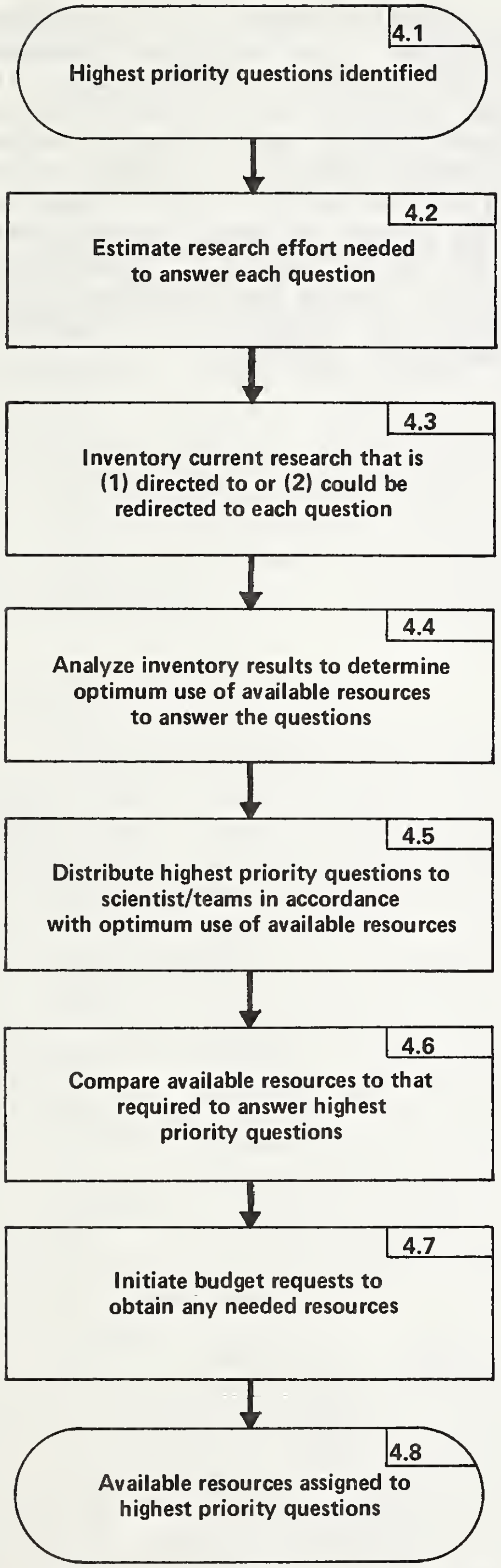

Figure 5.--Systematic process for allocating resources.

primarily to generate the information necessary so decisionmakers can execute activities 4.5 and 4.7.

The process begins after priorities have been established. Thus either those questions considered top priority or a ranking of questions should exist. If the latter, some judgment will be required regarding how many questions should be considered when activity 4.2 is executed. Without some limitations on a large hierarchy of questions, the workload may become unmanageable. Estimating effort required to answer a question is always iffy for research. Nevertheless, appropriate research scientists should be involved to make the best estimate of research scientist years required to answer each question. Even though the estimate may be in considerable error, it is essential that it be made so that activities 4.4 and 4.6 can be completed.

The decision about what should be done begins when activity 4.3 is executed. In most instances, scientists or their immediate supervisors will be required to determine if their work is directed to specific questions. Research managers and interest groups may need to be involved in determining what current work could be redirected. If the planning effort involves more than one research organization, making the inventory will be even more difficult. However, it must be made if activities 4.4 and 4.6 are to be done effectively.

No standard methods appear to exist for executing activity 4.4. Nor do any guidelines exist on who should execute 4.4. Depending on the number of organizations involved and the complexity of the area, probably either a staff group or the decisionmakers involved in 4.5 should execute 4.4. A staff could make an analysis and recommend to decisionmakers or the decisionmakers themselves could make the analysis. In either situation, the analysis will need to balance priority, total research effort required,

and availability of both quantity and type of scientific expertise and facilities in order to establish an optimum distribution. Determining the optimum distribution is an important decision that is part of activity 4.4. Although activity 4.6 is shown sequential to 4.5, it could be executed at the same time and by the same persons that execute activity 4.4. It also contains an important decision of what to include in a budget request, but for simplicity reasons it is not shown separately. In the total research planning process, probably only the actual planning and executing of experiments have more overall impact than do the decisions involved in activities 4.4 and 4.6. Thus these decisions should be formally and systematically made because of their importance in linking the planning of experiments to critical and important researchable questions.

Chapter 4—PLANNING EXPERIMENTS

Experiment is defined here to include all the precise methods of science discussed in chapter 2. It does not have the restricted meaning used in chapter 1. The scientists who conduct the experiments should do the planning. The how and who systems are much better defined for activity 5 than for activities 1-4 in figure 1. But, following systematic procedures can sharpen experiments to increase their efficiency; several are presented in this chapter.

A Systematic Planning Process

A systematic process for planning experiments is shown in figure 6. The process begins by recognizing that a question may be either hypothesis or measurement. The systematic process also recognizes that research can be executed only if a practical experiment can be proposed. If a practical experiment--one that can be executed with existing resources and methodology--cannot be proposed, further subdivision of a question is required. Consequently, activities 5.6-5.10 further subdivide questions when necessary. Stated another way, a scientist is, in essence, starting at activity 2 in figure 1 and simply following the generalized research planning process but in a smaller area.

Activity 5.11 is not a part of the scientific method as first proposed by Sir Francis Bacon, but it is a part of commonsense and clear thinking. Only certain things can happen when an experiment is conducted. Anticipating what might happen and comparing the anticipated results with the original question to be answered is a checkpoint on the adequacy of planning. When proposing experiments and anticipating the conceivable results, one should imagine how an experiment might be conducted. Ways to actually conduct the experiment are considered in activity 5.14, which involves hardware, scheduling, and all the detailed planning to actually conduct an experiment. When alternative ways have been identified, activity 5.15 follows, wherein the best experiment is selected. In decision activity 5.16, the facilities, equipment, technical expertise available, and budget constraints are all considered. With a "yes" decision, the research planning is completed as indicated in 5.17 of figure 6.

Use of Statistics

Statistical concepts and procedures have special importance when planning experiments. Unfortunately statistical procedures are often used only after an experiment has been conducted and the results are being interpreted. To be most effective, statistics should be considered when planning an experiment, before it is conducted.

The use of statistics when planning can be enhanced by recognizing that two types of hypotheses exist. The first is a scientific hypothesis--an unproved theory, supposition, or proposition tentatively accepted to explain certain facts. The second is a statistical (null) hypothesis--an exact statement capable of experimental disproof that provides the basis for conducting an experiment so that an unambiguous statistical test of significance can be made. Fully understanding the differences will clar-

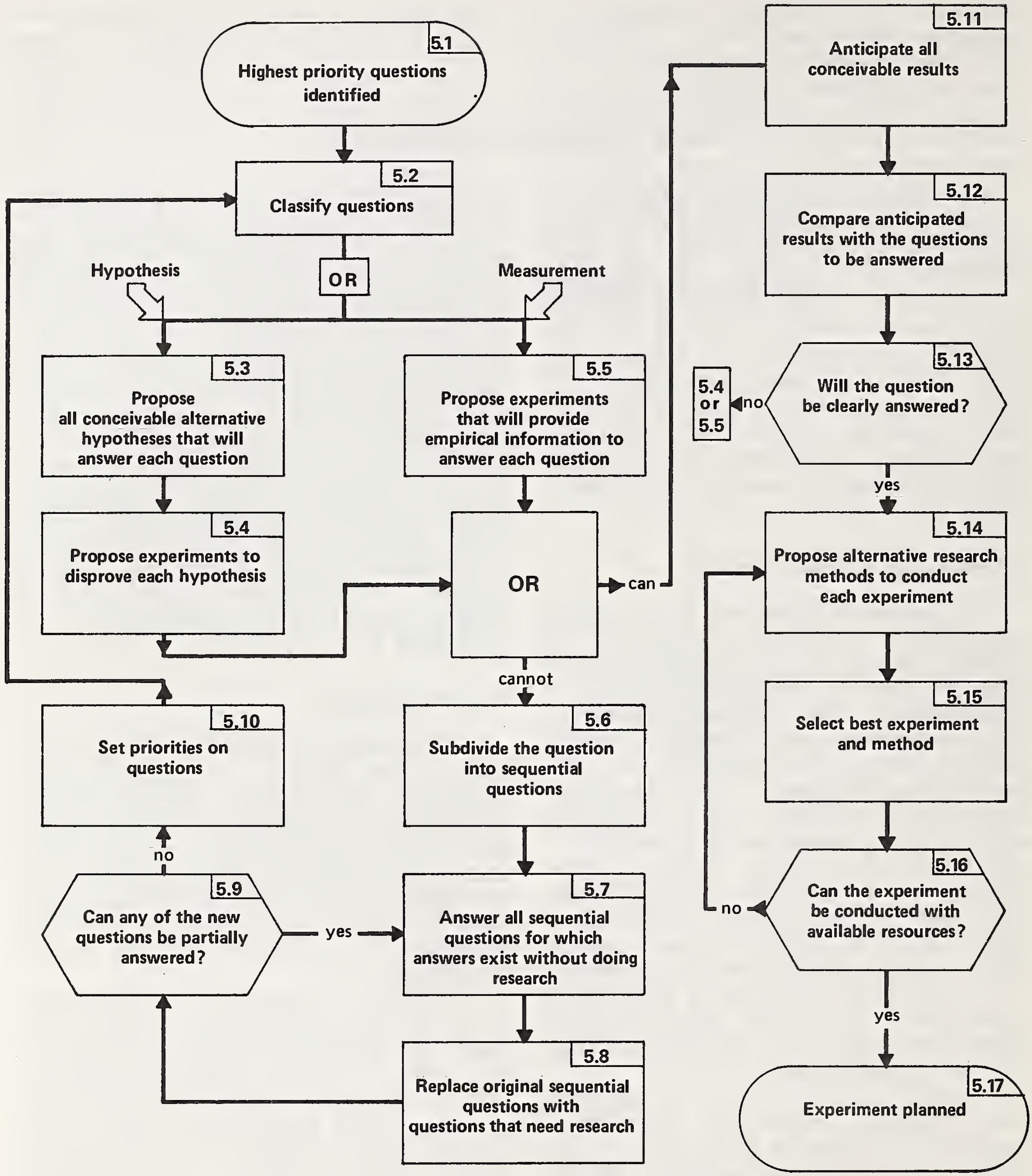

Figure 6.--Systematic process for planning experiments.

ify the role of statistics in planning and executing experiments.

The difference between these two types of hypotheses can be illustrated by two classical statistical designs that are reported in "The Design of Experiments" by R. A. Fisher, published in 1949 by the Hafner Publishing Company, Inc. In the first design, a lady proposed that she can determine whether milk or tea is first added to a cup. The scientific hypothesis is--the lady can discriminate whether milk or tea is first added to a cup. One possible experiment to test the hypothesis is to prepare eight cups, four in each way, and then have the lady taste them and indicate the way each was prepared. The experiment is simple to carry out. However, since 70 ways exist for choosing 4 objects out of 8, by pure chance the lady could be right 1 time in 70 or about 1.4 percent of the time. She also may claim that she does not have absolute discriminatory power but is correct most of the time. Therefore the hypothesis cannot be conclusively proved since no clear-cut way exists to eliminate chance or to measure partial discriminatory power. To get around the dilemma, one can state a statistical (null) hypothesis that is related to the scientific hypothesis. In this instance--the lady has no discriminatory power to determine if milk or tea is first added to a cup. In other words, the lady's judgments are not influenced by the order in which milk or tea is added to a cup and she is always wrong. For this hypothesis, only one right judgment by the lady is required to disprove it. By testing the number of times her judgment is right and comparing the number right with the probability of being right based on pure chance, a statistically valid acceptance or rejection of the hypothesis can be made. Another statistical hypothesis can be made that brackets the scientific hypothesis or in effect "contains the scientific hypothesis." It is--the lady is always right in her judgment. Thus two statistical (null) hypotheses can be tested and they are (1) she has absolute discriminatory power and is always right or (2) she has no discriminatory power and is always wrong. These two hypotheses bracket or contain the nontestable scientific hypothesis that she has discriminatory power.

Another example given by Fisher involves the scientific hypothesis that crossbred plants grow more rapidly than inbred plants. A possible experiment is to grow both crossbred and inbred plants under the same conditions and measure the height of each plant after a suitable period of time. The difficulty with the experiment is that no two plants within the crossbred or inbred types will likely be the same height. In other words, normal variation prevents making any clear unambiguous conclusions; thus the scientific hypothesis cannot be proved. Again, a statistical hypothesis can be stated--if the crossbred and inbred plants are increased indefinitely, the average height of the crossbred plants will be equal to that of the inbred plants. The mirror statistical hypothesis that brackets the scientific hypothesis is--the average of the crossbred plants will be greater than that of the inbred when the number is increased indefinitely. Only one different average is required to disprove the first hypothesis and only one same average is required to disprove the second. The statistical theory of errors (as t test, normal distribution, or analysis of variance) can be used to determine if either statistical hypothesis can be accepted or rejected. Thus when a hypothesis question is involved, the scientific hypothesis should be restated as a statistical hypothesis. They are related but different. Appropriate sta-

tistical designs then can be used to clearly and unambiguously accept or reject the statistical hypothesis.

A systematic process for designing an experiment when a hypothesis is involved is illustrated in figure 7 in activities 5.4.1-5.4.7. As shown, the process begins with a scientific hypothesis, proceeds through the conceptualization of one or more experiments, which then leads to stating a statistical hypothesis that in turn provides the basis for the statistical design of an experiment. In most instances, several iterations are required so that in real life the sequence of steps becomes blurred and is almost one step. That blurring can be the cause of poorly designed experiments. A researcher is well advised to seek statistical consultation when in the planning stages rather than after an experiment has been conducted and data are being analyzed. In fact, if a researcher does not have some statistical expertise, activities 5.4.4-5.4.6 should be done by a qualified statistician. Note that having these activities done by a statistician does not relieve nor reduce the responsibility for creativity and control of the experiment by the researcher. The researcher will be involved and responsible for activities 5.4.1-5.4.3 in figure 7 and all activities in figure 6.

Figure 7 also illustrates in activities 5.5.1-5.5.5 a systematic process for designing an experiment when a measurement rather than a hypothesis question is involved. A measurement question usually will involve asking "how much" or "where is" something happening. For example, where is the fertilizer going that is applied to a crop (in the plant, air, soil, or ground water)? Because no hypothesis is involved, the statistical approach is somewhat different. As indicated in activity 5.5.3, the statistical emphasis is to establish the reliability of the data, not accept nor reject a statistical hypothesis. This reliability requirement also exists when a test as defined in chapter 1 is conducted, and the reliability should be clearly established.

Establishing reliability of data involves three general factors. The first is assuring that the experiment is free from bias. That is usually accomplished by technical control that assures that similar conditions are in fact similar, or randomized, or both. The second factor is establishing a measure of error in the data. Variance, standard deviation, degrees of freedom, and normal distribution are statistical terms related to measures of error. The third general reliability factor is establishing sufficient accuracy to accomplish the purpose of the experiment. Accuracy generally involves sample procedures, replications, or both. These three factors are also involved in hypothesis experiments, but there the guidance for reliability comes from the statistical hypothesis. For a measurement experiment, however, the researcher must establish what is acceptable reliability. Just as for a hypothesis experiment, statistical consultation is highly desirable for a measurement experiment. Activities 5.5.3 and 5.5.4 could well be turned over to a statistician by a researcher if the researcher has limited statistical expertise. In fact, if either a hypothesis or a measurement experiment is not properly designed, the results of the experiment might better be described as an experience and used as the basis to plan a new experiment that will be worthy of reporting to science.

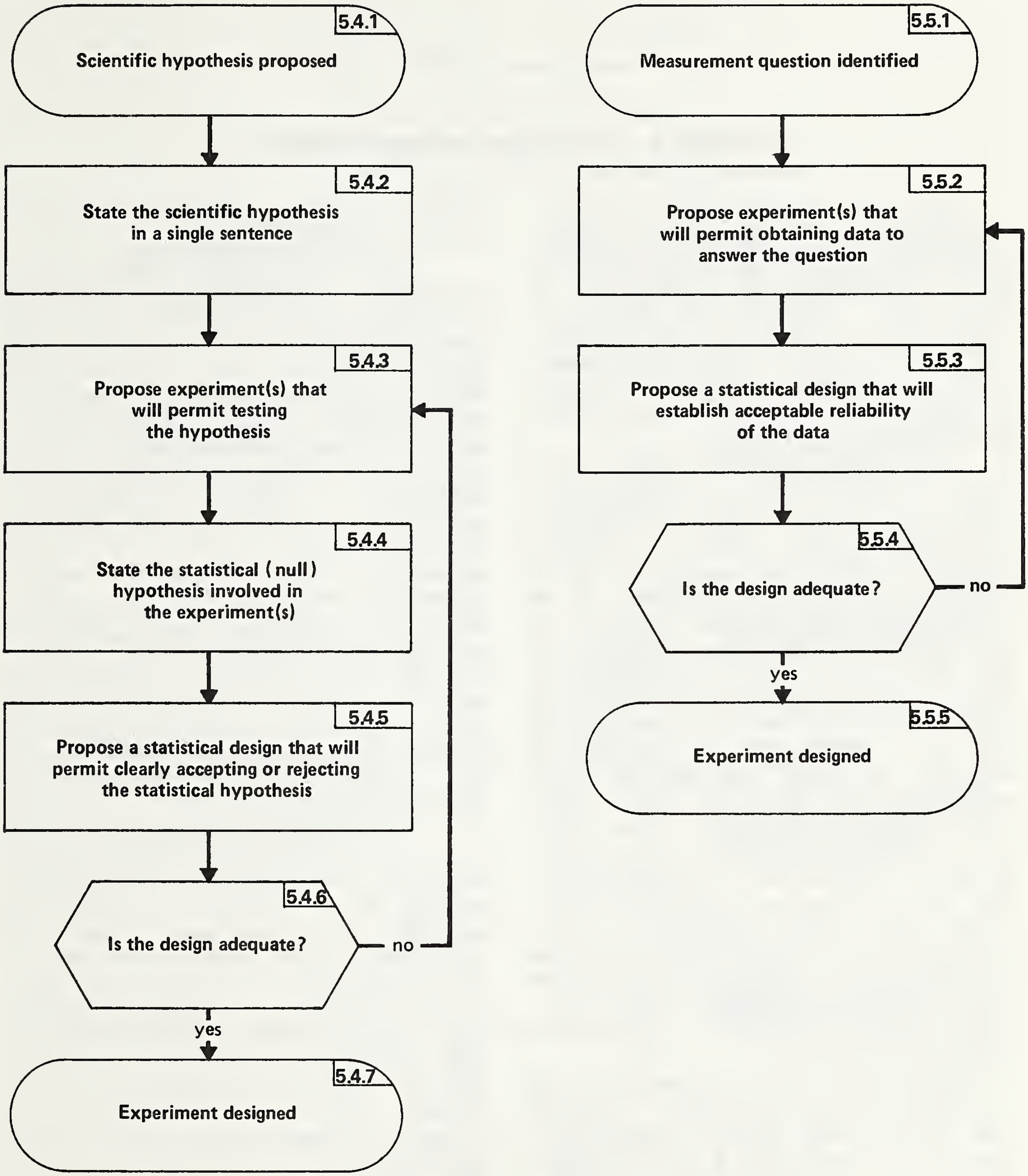

Figure 7.--Systematic process for designing experiments.

CHAPTER 5—EVALUATING RESEARCH RESULTS

Evaluation begins after the experimental results have been analyzed, interpreted, and reported--after the actual execution of experiments is completed. Although the activities identified in figures 2-7 are continuous, a significant gap exists between the last activity in figure 6 (activity 5.16) and evaluation, which begins with decision activity 6.

Evaluation involves answering the three decision questions identified in activities 6-8 in figure 1. However, depending on the answer to decision question 6, decision questions 7 and 8 may not need to be answered in an evaluation. Also, as was true for activities 2-4 discussed in chapter 3, the scope of the area will greatly affect how the evaluation should be done. Thus who makes an evaluation, how the information is obtained to make the decisions, and how the decisions are made will and should vary. For example, if only one or two scientists identified an area, they should be able to make the complete evaluation and can do so informally. If a large complex area is identified, others besides the scientists conducting the experiments likely should become involved and the how part of the system should be much more formal and structured.

Regardless of the complexity of the area, the scientists who conducted the experiments should answer the question in activity 6 of figure 1. The issue to be determined is whether the planned research objectives have been achieved. Seldom will that have occurred since normally several questions will need to be answered, so the decision normally will be "no." No special procedures or concerns are involved and the decision should be quickly and easily made.

The single question identified in activity 7 of figure 1 is a sequence of smaller more specific questions that are illustrated in figure 8. The process contains two loops beginning with decision questions 7.2 and 7.7, respectively. Both questions must always be answered to solicit information to make the overall decision in activity 7. Also, if the answer to decision question 7.4 is no, both decision questions 7.5 and 7.10 must be answered. In large complex areas, scientists involved with the experiments, their immediate supervisors, or both usually should have the information to answer decision questions 7.2 and 7.7. Thus they should make the yes-no decisions. Similar reasoning applies to decision questions 7.3 and 7.8. However, if the loop containing decision questions 7.4-7.6, 7.10, and 7.11 is entered or if decision question 7.9 is to be answered, research managers (not scientists and their immediate supervisors) are in the best position to objectively answer the questions. Thus depending on the answers to each of the decision questions 7.2-7.11, a number of people could be involved in executing decision activity 7 in figure 1 when large complex areas of research are involved. Initiation of the evaluation activity, however, rests with the scientists who just completed a planned experiment.

If the answer to the question in activity 7 of figure 1 is "no," the evaluation continues. As was true for decision question 7, decision question 8 can best be answered by answering a sequence of smaller questions; they

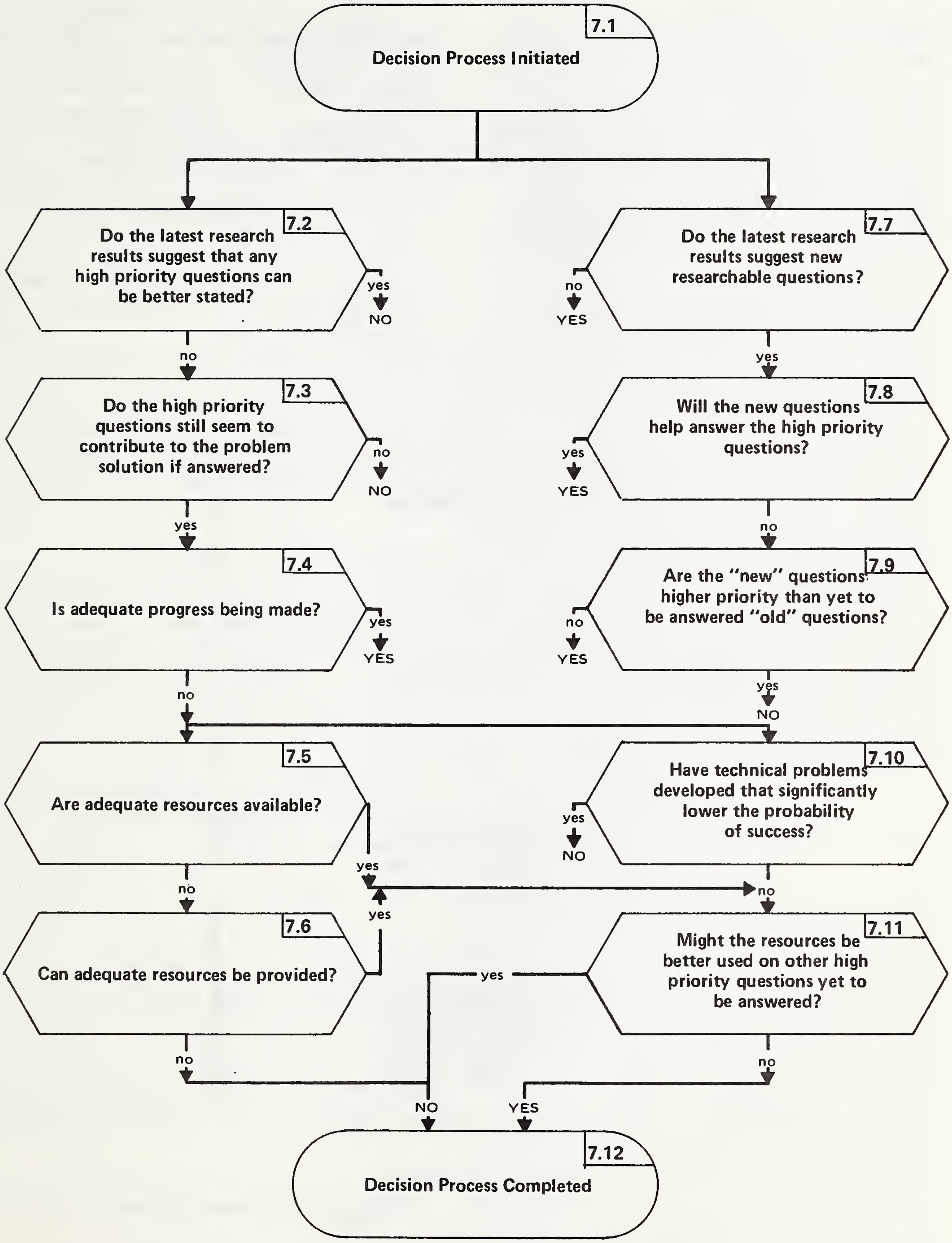

Figure 8.--Systematic process for deciding if the right questions have been asked.

are shown in figure 9. All these questions can best be answered by research managers when large complex areas are involved and so managers should make the yes-no decisions. If the overall answer is "yes," previous planning efforts will need to be reviewed but not necessarily redone. If the answer is "no," the entire planning effort will need to be redone. A "no" answer in effect indicates circumstances have changed so much that major replanning is required and the planned research effort may need to be terminated. The procedures discussed in the section on identifying an area of research should then be applied to begin the research planning process for a new full iteration.

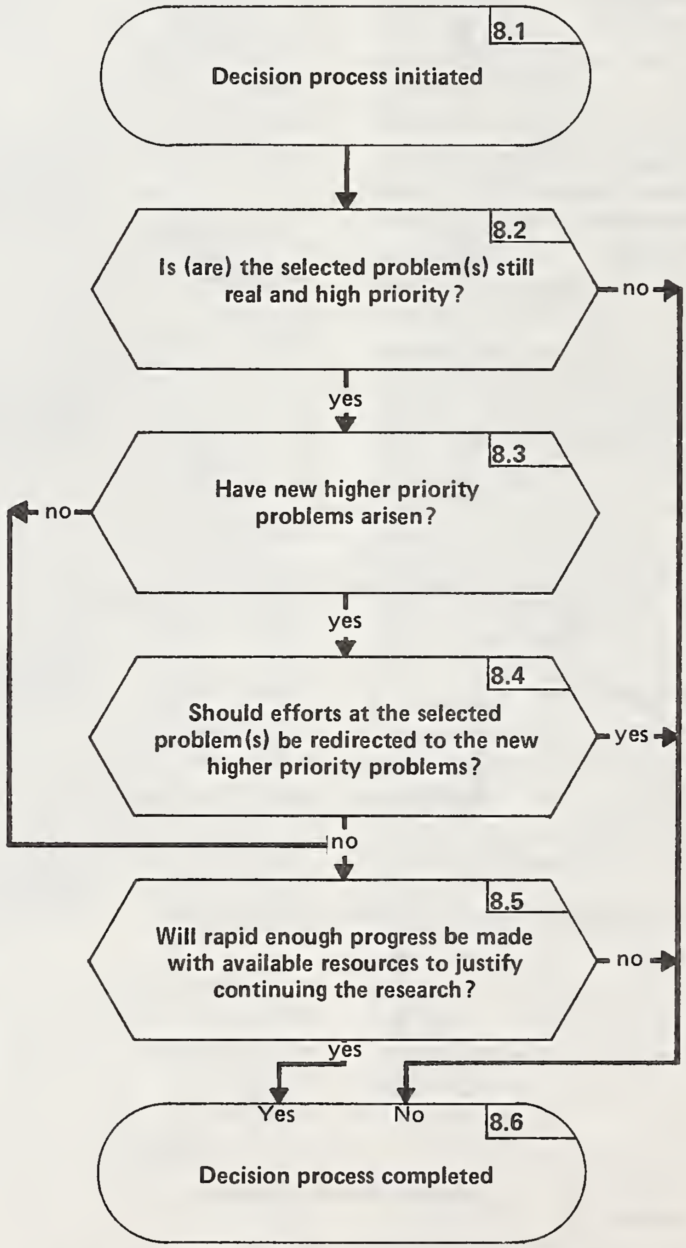

Figure 9.--Systematic process for deciding if an area is still worthy of research.

CHAPTER 6—AN EXAMPLE OF PLANNING RESEARCH IN AN AREA

The most difficult part of research planning is developing a hierarchy of questions. Yet if balance between control from the top and freedom at the bottom is to be achieved, it will have to occur in developing and accepting a hierarchy of questions as the basic planning structure. This chapter illustrates how the principles for systematically planning research in an area can be applied. Developing a hierarchy of questions is the main activity in planning research in an area.

The illustration is based on a real situation that occurred in 1972 where the techniques were applied by a small group of research scientists and administrators. In terms of the general situations described in chapter 2, this example probably falls between situation 1 and 2. The area is more complex than one or two scientists could cover but less complex (the breadth of expertise involved) than a small group of research supervisors could handle. The illustration was accomplished in an informal workshop lasting about 2 days where the generalized research planning process was used as the agenda for the meeting. The techniques in following activities 1-4 of the generalized research process in figure 1 are described to show planning in an area, particularly the development of a hierarchy of questions. Each activity is discussed separately, with most discussion on activity 2.

Activity 1—Area for Research Identified

When Cuban sugar became unavailable to the United States in the 1960's, sugarcane production in the muck soils of southern Florida was greatly increased. Because the muck soils are so loose, the cane does not grow upright but usually each stalk grows somewhat parallel to the ground for a short distance before rising vertically. Hence the name recumbent sugarcane is often applied. A shortage of labor to hand-harvest the recumbent cane, primarily to cut the stalks from the roots, triggered research efforts to mechanize the harvesting operations. After several years of research, a planning effort was initiated by common agreement of the scientists involved and the responsible supervising officials because considerable progress had been made but major obstacles still remained. A reevaluation of the research area seemed justified and was the reason for undertaking research planning and simultaneously identifying the area to be planned.

Activity 2—Develop a Hierarchy of Questions That Need Answering

The systematic process illustrated in figure 3 was closely followed as the agenda for discussion. The key points made during the discussion are reported here so that the rationale used by the group should be reasonably apparent. Since the intent here is to illustrate the process, the reader should not let disagreement with any of the rationale or the fact that the situation has changed in the intervening years obscure the principles of the process that are illustrated. To make the development of the hierarchy easier to follow, we present the completed hierarchy first. It consisted

of three alternative solutions, of which only one was fully developed. The fully developed solution had lowest level questions at either the third or fourth level. The hierarchy is:

Problem: Present harvesting methods do not allow maximum sugar recovery per acre at the mill.

- I. How can the need for sugarcane production in muck soils be lowered or eliminated?
- II. How can milling processes be altered to accept the harvested product?
- III. How can current sugarcane harvesting methods be improved?
  - A. How can cutting cane from the roots and leaving an acceptable stubble be improved?
    - 1. How can rotary cutting blades be automatically controlled so that the cutting height is properly maintained?
      - a. What is a workable method to sense position?
      - b. What are performance characteristics of the system?
    - 2. How can the tendency for rotary cutting blades not to cut be reduced?
      - a. Will very high speed cutting work?
      - b. Can a shear bar be incorporated in the cutting mechanism?
    - 3. How can the vulnerability of rotary cutting blades to damage be reduced?
      - a. Can an operator incentive system be devised?
      - b. Can a counterbalance mechanism with an inertial snubber be developed?
  - B. How can separation of tops from the stalk be improved?
    - 1. How can cane be grown erect so a topping blade can be used?
      - a. What cultural practices will enhance a good rooting system?
      - b. To what extent can more erect varieties be developed?
    - 2. Can recumbent cane be oriented so that most tops can be located and cut off?
    - 3. What are the criteria for cutting the stalk in short pieces and separating by moving air?
      - a. How short must lengths be so the top is isolated?
      - b. What are the suspension velocities of tops and stalks?
      - c. How close can the suspension velocities be maintained in a chamber when cane is passed through?
      - d. What are the flow velocities required to convey?
      - e. Are differentials in separating velocities large enough to permit efficient separation?
      - f. What mechanisms will enable controlling air velocity so separation is achieved?
    - 4. What are the criteria for cleaning rolls?
      - a. What size, speed, surface geometry, and spacing will pull tops through rolls but not stalks?
      - b. What lengths of

cane pieces will aid in removing tops?

c. How can stalks and tops best be positioned over the rolls?

C. How can separation of leaf trash from the stalk be improved?

1. How can controlled burning be accomplished?

a. What temperatures and exposure time are needed to remove leaf trash?

b. What temperatures and exposure time can stalks tolerate without sugar loss?

c. At what point in the harvest cycle could controlled burning be done?

d. What mechanisms could be used to control burning?

e. What will controlled burning cost?

2. What are the criteria for cutting the stalk in short pieces and separating by moving air?

a. How short must lengths be so leaf trash is isolated?

b. What are the suspension velocities of leaf trash and stalks?

c. How close can suspension velocities be maintained in a chamber when cane is passed through?

d. What are the flow velocities required to convey?

e. Are differentials in separating velocities large enough to permit efficient separation?

f. What mechanisms will enable controlling air velocity so separation is achieved?

3. What are the criteria for cleaning rolls?

a. What size, speed, surface geometry, and spacing will pull leaf trash through rolls but not stalks?

b. What lengths of cane pieces will aid in removing leaf trash?

c. How can stalks and leaf trash best be positioned over rolls?

D. How can separation of foreign matter from the stalk be improved?

1. What are the criteria to separate foreign material using moving air?

a. How short must lengths be so foreign matter is isolated?

b. What are the suspension velocities of foreign matter and stalks?

c. How close can suspension velocities be maintained in a "chamber" when cane is passed through?

d. What are flow velocities to convey?

e. Are differentials in separating velocities large enough to permit efficient separation?

f. What mechanisms will enable controlling air velocity so separation is achieved?

2. What are the criteria of a spike-tooth cylinder conveyor for separation?

a. What combination of cylinder diameter, shape and length of spike, cylinder speed and spacing, number of cylinders, and slope will allow 3-inch openings for material to fall through and knock off dry leaves?
b. What length of stalk will minimize cane loss and damage for this combination?
3. What are the criteria for using screens to separate?
a. What size and shape of flat screen opening will permit 2- to 3-inch clods of soil, rocks, and other trash to pass but not stalks of cane?
b. Where in the harvesting system would a flat screen be most effective?
E. How can transport of the stalk to the mill be improved?
1. How can field wagons be made longer and flotation increased?
2. How can trucks be made more compatible with field wagons so inefficiencies are reduced?

Developing the hierarchy began by writing a problem statement (activity 2.2), and the background information under activity 1 provided part of the basis. Additional information that was discussed included: (1) The highest sugar content in a stalk is at the bottom next to the roots, and because 2 to 3 years of growth can be obtained from the same roots and thereby eliminate the necessity to replant every year, cutting the stalk next to the root is critical, (2) excess foreign material in the stalks delivered to a sugarcane processing mill interferes with the sugar recovery processes involved, and (3) experience indicates that mechanical harvesting tends to increase the amount of trash delivered to a processing mill. The overall objective was identified as getting the maximum sugar recovery per acre at a mill. Harvesting methods were identified as an obstacle in achieving that objective. Consequently, the problem statement developed was: Present harvesting methods do not allow maximum sugar recovery per acre at the mill.

When alternative solutions (activity 2.3) were discussed, some of the points considered were the lowered quality of the cane delivered to the mill, the possibility of altering milling processes, and the feasibility of shifting sugar production out of the muck areas to avoid recumbency, which might be triggered by lowering the demand for sugar. It was concluded that three problem solutions existed, although one might more appropriately be termed a problem elimination. The alternatives are expressed in the following three questions:

I. How can the need for sugarcane production in muck soils be lowered or eliminated?
II. How can milling processes be altered to accept the harvested product?
III. How can current harvesting methods be improved?

The next activity (2.4) required subdividing the solution questions into independent subquestions. The solution implied by question I raises many complex issues. Pursuing that solution would require concurrence of the producers (farmers) and could have a significant impact on the U.S. sugar industry. Furthermore, the sugar industry is carefully regulated by the Federal Government. Thus it was concluded that subdividing question I would be of little value since re-

search would be of limited value in helping achieve the implied objective.

When question II was discussed, it was noted that diffusion and crushing are the two methods used to extract cane juice. The economics for sugarcane processing seems to be about equal for each method, and to be effective either one requires the same high quality product. Thus no major advantage or effect on a harvesting system should result from the adoption of either method by the sugarcane mills. Also, mill processing research can most effectively be accomplished by those associated with the mills. Since the research efforts for the program being reviewed were directed toward harvest methods and no facilities for processing mill research were available, further mill processing research planning did not seem appropriate. Thus a decision was made not to subdivide question II (activity 2.4).

Subdivision of question III was approached by defining the system involved in the production of sugar from cane. A qualitative system was defined by identifying the essential events that are required. These involved, in sequence, planting, growing, harvesting, transporting to the mill, and milling. Because of the ratooning capabilities of the sugarcane plant, replanting and regrowing are two other events that occur. All events must occur in a specific sequence and they are independent of each other in that each is done in a different manner and controlled by different variables. Harvesting as a unique event can be subdivided into three essential events, which are: Cut stalks from the roots, separate leaf trash, and separate tops. The transport event can be subdivided into the actual transport activity and separation of foreign material, which includes anything other than leaf trash or cane tops. The five events identified (three from harvest and two from transporting to the mill) are the minimum that must be executed in the harvesting and transporting to the mill operations. The harvest events can be done in any order, cutting must precede transport, and the separation of foreign material must occur someplace between cutting and arriving at the mill. Based on the system definition, question III was subdivided (activity 2.4) into the following independent questions:

A. How can cutting cane from the roots and leaving an acceptable stubble be improved?
B. How can separation of tops from the stalk be improved?
C. How can separation of leaf trash from the stalk be improved?
D. How can separation of foreign matter from the stalk be improved?
E. How can transport of the stalk to the mill be improved?

An examination of each of the five independent questions to see if further independent subdivisions could be made (activity 2.5) indicated that the next level of subdivision gets into specific methods that might be used. Although the methods could be considered independent, little advantage could be seen to further subdivide, particularly since one of the objectives was to develop as simple a hierarchy of questions as possible. Consequently, it was decided that no further independent subdivisions could be made. Note that questions I, II, and III are fully independent alternatives and possibly even mutually exclusive. On the other hand, questions A-E are only independent.

For the same reasons that were discussed in the previous paragraph, it was concluded that no new problem statements could be written (activity 2.6).

At this point in developing the hierarchy of questions, the strategic planning had been completed since the identification of alternatives had

been exhausted. Completing the process required further subdivision of the questions by identifying sequential rather than alternative questions. Simultaneous elimination of answerable questions also was begun. Thus activities 2.7 through 2.10 were applied in turn to the five questions III.A-E and recycled as necessary. To present the process, each major question is dealt with in its entirety by cycling and recycling through the sequence so as to provide continuity. To execute the process, each activity could be applied to each question before proceeding to the next activity. Or, as was actually done by the group that did this example, the sequence could be applied to each question in turn for one cycle (to but not through activity 2.10) and then a second and third cycle applied. Obviously other combinations are possible, and all that is required is to systematically apply the sequential activities in the correct order until all questions have been subdivided as far as is possible.

Question III.A - How can cutting cane from the roots and leaving an acceptable stubble be improved?

The sequential questions listed for question III.A (activity 2.7) were: What methods are presently used, what is wrong with them, and how can they be improved? The answers to these three questions (activity 2.8) are:

> Only two methods are presently used, a machete and a rotary blade. The machete requires high labor input and often the cut is made too high. The rotary blade requires careful adjustment of the cutting height, it tends not to cut and the cane is pulled out by the roots, and the blade is vulnerable to damage. Better and more skilled laborers would make the machete more effective and it might be possible to make the cane easier to cut. The rotary blade needs automatic control of its cutting height in order to correct its tendency not to cut and vulnerability to damage.

Based on the answers, the original questions were replaced (activity 2.9) with the following:

1. How can rotary cutting blades be automatically controlled so that the cutting height is properly maintained?
2. How can the tendency for rotary cutting blades not to cut be reduced?
3. How can the vulnerability of rotary cutting blades to damage be reduced?

Each of the questions was examined and it was concluded they could be partially answered (activity 2.10). Thus each needed to be cycled through activities 2.7-2.10. The following sequence of questions was listed for question III.A.1: What height limits exist, what methods exist to sense position, what mechanisms can be used to control height, and how does each mechanism perform? The answers are:

> The cutting height should be at ground level plus or minus one-half inch. Gage wheels, skids, proximity sensors, and torque to turn the cutting blade are methods that have been used to sense position. Mechanical, hydraulic, pneumatic, and electrical mechanisms can be used to control height.

Based on these answers, the following two questions (activity 2.9) were listed:

a. What is a workable method to sense position?

b. What are performance characteristics of the system?

Examination of the questions indicated that they could not be partially answered (activity 2.10), so the sequence did not need to be recycled.

Developing the hierarchy was continued by returning to question III.A.2., and the following sequence was listed (activity 2.7): Why don't

they cut now and what can be done to correct the situation? The answers are:

Loose soil and shallow roots contribute to the tendency not to cut although no satisfactory data exist to verify the suspicion. A shear bar might be needed for the cutting blade to operate against to improve cut. Possibly very high speed could be used. Based on the answers, the following questions were listed (activity 2.9):

a. Will very high speed cutting work?

b. Can a shear bar be incorporated in the cutting mechanism?

Examination of the questions indicated that they could not be partially answered, so the process was continued by returning to question III.A.3.

The following sequence of questions was listed for question III.A.3: What is causing the damage, can the cause be removed, and how can the cause be corrected? The answers are:

Dropping a cutting blade on the ground and striking obstacles cause breakage. Obstacles usually can be removed from a field although that may not be practical at the ends of rows on roadways. Drop breakage might be corrected using a counterbalance mechanism with an inertial snubber, operator incentives, or a safety stop. Obstacle damage might be reduced with operator incentives, improved materials, a shear pin, or the problem minimized if broken parts could be replaced easier.

Based on these answers, the following questions were listed (activity 2.9):

a. Can an operator incentive system be devised?

b. Can a counterbalance mechanism with an inertial snubber be developed?

Examination of the questions indicated that they could not be partially answered. Activities 2.7-2.10 had been applied to all lowest level questions until a no decision on each had been made. Thus the hierarchy under question A was considered completed.

<u>Question III.B</u> - How can separation of tops from the stalk be improved?

The sequential questions listed under question B were: What methods are presently used, what is wrong with them, and how can they be improved? The answers to these questions are (activity 2.8):

Present methods involve cutting by hand with a machete, using mechanical topping blades, cutting the stalks into short lengths and separating tops and stalks by air, and passing material over cleaning rolls to pull out the tops. The machete requires large amounts of labor. Mechanical topping blades only work in erect cane of uniform height. The cut-and-separate-by-air method has not been used enough nor are enough basic data available to determine what is wrong. Cleaning rolls are difficult to construct so that they are mechanically reliable, and when a small differential exists between the size of the stalk and the tops, the rolls tend to choke. The problems with the machete can only be solved by mechanizing. Mechanical topping blades would be more effective if the cane could be grown erect or some method could be developed to feed the cane into a machine in an erect position. More basic information is needed before improvements can be suggested for the cut-and-separate-by-air or cleaning-roll methods.

Based on these answers, the original questions were replaced with the following:

1. How can cane be grown erect so a topping blade can be used?

2. How can cane be fed more erect into a harvesting machine?

3. What are the criteria for cutting the stalk in short pieces and separating by moving air?

4. What are the criteria for cleaning rolls?

Each of the questions was examined and it was concluded they could be partially answered (activity 2.10), so the development was continued by listing the following sequence of questions to question III.B.1: Why doesn't cane grow erect and how can the cause be corrected? The answers are:

> Generally the cane grows too tall, it may have low fiber content, or a poor root system develops so that it can't support the stalk. Changes in cultural practices might enhance a better rooting system. Minor improvements might be made in erectness from a breeding program. Growing in a "stronger" soil would help.

Based on these answers, the original questions were replaced with the following (activity 2.9):

a. What cultural practices will enhance a good rooting system?

b. To what extent can more erect varieties be developed?

Examination of the questions indicated that they could not be partially answered so activities 2.7-2.10 did not need to be applied.

The development proceeded by listing the following sequence of questions for question III.B.2: What principles can be used to orient and what mechanisms will exploit the principles? The answers are:

> A gradual lifting, gathering, and compression of the cane into an upright position before cutting from the ground would help accomplish orientation. After a stalk is cut, it could be routed through an orientation device. Leaves on the top of a stalk could be held by suction against a moving screen so the stalk could be pulled into a desired position.

Based on the answers, it was decided that the question could not be subdivided, but the original question could be revised as follows:

III.B.2. Can recumbent cane be oriented so that most tops can be located and cut off?

Obviously the question could not be partially answered, so recycling was not necessary.

The development continued by listing the following sequence of questions for question III.B.3:

a. How short must lengths be so the top is isolated?

b. What are the suspension velocities of tops and stalks?

c. How close can the suspension velocities be maintained in a chamber when cane is passing through?

d. What are the flow velocities required to convey?

e. Are differentials in separating velocities large enough to permit efficient separation?

f. What mechanisms will enable controlling air velocity so separation is achieved?

None of the questions could be answered (activity 2.8). Therefore none of the questions could be replaced (activity 2.9). Furthermore, since the sequence would fully answer the broader question if answers could be obtained, it was concluded that recycling was not necessary.

The development of the hierarchy continued by listing the following questions for III.B.4: Is it possible to remove the top without pulling the stalk through the rolls, what length of cane pieces is needed to best isolate the tops, what size differential in stalks can be separated by cleaning rolls, and how can stalks best be conveyed over cleaning rolls? When trying to answer the questions, it was concluded a different sequence would be better. The new sequence was:

a. What size, speed, surface geometry, and spacing will pull tops through the rolls but not stalks?

b. What lengths of cane pieces will aid in removing tops?

c. How can stalks and tops best be positioned over the rolls?

The answers to the questions are:

> A diameter size of approximately 6 inches and a speed of approximately 450-550 rpm's seem to be best. Not much is known about the surface geometry or spacing. Leaves must be grabbed so that relatively close spacings are required. However, with tight spacings it is difficult for large quantities of material such as immature tops to pass through the rolls.

Although the answers provided some information, it was concluded that not enough information was available so that the original questions could be replaced with better ones. Thus the full hierarchy under question B was considered complete.

Question III.C - How can separation of leaf trash from the stalk be improved?

The development of the hierarchy of questions for III.C was begun by listing the following sequence: What methods are presently used, what is wrong with them, and how can they be improved? The answers are:

> Present methods involve burning, removing by hand with a machete, air separation, and cleaning rolls. Burning causes air pollution, doesn't burn all the green material, and can cause the soil to burn. Air separation has the same difficulties for leaf trash as it does for tops. Cleaning rolls have particular difficulty in grabbing the leaf material. Most of the discussion of top removal by separation under question III.B.3 is also applicable to leaf removal. Air pollution may only look bad because the smoke is visible but little data exist on the amount of pollutants created. Desiccants might help reduce the amount of green material. Possibly controlled burning could be used.

Based on these answers, the original questions were replaced with the following:

1. How can controlled burning be accomplished?

2. What are the criteria for cutting the stalk in short pieces and separating by moving air?

3. What are the criteria for cleaning rolls?

Examination of the questions indicated they all could be partially answered (activity 2.10), so the development was continued by listing the following sequence for question III.C.1:

a. What temperatures and exposure time are needed to remove leaf trash?

b. What temperatures and exposure time can stalks tolerate without sugar loss?

c. At what point in the harvest cycle could controlled burning be done?

d. What mechanisms could be used to control burning?

e. What will controlled burning cost?

When trying to answer the questions, it was concluded that some information exists for a and b and essentially none for c, d, and e. Since c, d, and e are completely dependent on the first two questions, however, it was concluded that the original questions were adequate and very little would be gained by completing activities 2.8-2.10.

The development of the hierarchy was continued by returning to question III.C.2. It was concluded that substituting leaf trash for tops would make the situation the same as was considered under question III.B.3. By similar reasoning it was concluded that with the substitution of leaf

trash for tops, the discussion under question III.B.4 would be the same as for III.C.3. Thus the hierarchy of questions developed under question III.B.3 and III.B.4 completed the hierarchy under III.C.2 and III.C.3, respectively, by substituting leaf trash for tops in the questions.

Question III.D - How can separation of foreign matter from the stalk be improved?

The following sequence of questions was listed under question III.D: What methods are presently used, what is wrong with them, and how can they be improved? The answers are:

> Present methods involve removal by hand, by air, by not picking the matter up in the first place, using a spike-tooth cylinder conveyor, screening, and water washing. Cleaning by hand has high labor requirements and air has high power requirements, the suspension velocities are not known, and most equipment is still experimental. Spike-tooth cylinders are still experimental. Screening is satisfactory only under dry conditions, and it has some limitations depending on the size of the matter to be removed. Water wash is only suitable for removing soil and it has associated disposal problems. Hand methods can be corrected by mechanizing, the air conveyor and screening methods need more research, and the water wash method could best be corrected by elimination.

Based on these answers, the original questions were replaced with the following:

1. What are the criteria to separate foreign material using moving air?
2. What are the criteria of a spike-tooth cylinder conveyor for separation?
3. What are the criteria for using screens to separate?

Examining the three questions indicated that all could be partially answered, and so the development proceeded to question III.D.1. It was concluded that substituting foreign material for tops would make the situation the same as was considered under III.B.3. Thus the hierarchy of questions developed under III.B.3 completed the hierarchy under III.D.1. by substituting foreign material for tops in the questions.

The development of the hierarchy of question III.D was continued by listing the following sequence under III.D.2: What material must be removed; what size of material pieces are involved; how much agitation is needed to separate the foreign material from the stalks; what combination of cylinder diameter, spike shape and length, cylinder spacing, number of cylinders, speed, and slope give the needed agitation; and what damage to stalks is done for each level of agitation. The answers are:

> Soil, rocks, root stools, and leafy trash are the foreign material. Soil and rocks are both 2-3 inches in diameter. Root stools vary from 3 to approximately 8 inches in diameter. Leafy trash is highly variable. The size of cane is approximately 1 inch in diameter, but the length can be adjusted by the cut that is made. Agitation required to remove soil is variable depending on the moisture content of the soil. Leaf trash and root stools probably can be separated if the mat of material is sufficiently disturbed through agitation. Because of considerable variation in size, probably only minimal agitation would be necessary to remove most foreign material except any dry leaves.

Based on the answers, it was concluded the original questions could be replaced with the following:

a. What combination of cylinder diameter, shape and length of spike, cylinder speed and spacing, number of

cylinders, and slope will allow 3-inch openings for material to fall through and knock off dry leaves?

b. What length of stalk will minimize cane loss and damage for this combination?

It was concluded that these questions could not be partially answered (activity 2.10), so the development proceeded to question III.D.3. When examining question III.D.3, it was concluded that the situation was very similar to that discussed under question III.D.2. Therefore the hierarchy for III.D.2 was considered completed by listing the following questions:

a. What size and shape of flat screen opening will permit 2- to 3-inch clods of soil, rocks, and other trash to pass but not stalks of cane?

b. Where in the harvesting system would a flat screen be most effective?

<u>Question III.E</u> - How can transport of the stalk to the mill be improved?

The sequence of questions developed for III.E was: What is involved in transport, what methods are used, what is wrong with the methods, how can they be improved, and do any other methods seem feasible? The answers are:

> Two general systems are employed. The first involves picking up cane in a heap row, with the independent events of pickup, load, haul, unload, and possibly clean. The second general system involves loading by a harvester, with the independent events of haul, unload, and possibly clean. In either system, time can be a constraint on transport operations in order to minimize deterioration. In the first system, pickup is performed by grab loaders or continuous loaders. The loading operation is performed by the same two types of equipment wherein the continuous loader serves as a conveyor. Hauling is performed in either system by a field wagon, truck, or both. Unloading is done with dumping or use of slings and applies to either system. Grab loaders require high labor inputs, they need entire straight stalks, high quantity losses can occur, squeezing of the cane can result, low density usually occurs in the wagon or truck, and trash may be picked up. A continuous loader requires a high investment, has large quantity losses, and needs clean straightly stacked cane. With continuous loaders, generally cane is chopped into shorter lengths to increase load density, but the chopping increases the chances of deterioration. Also, the continuous loader requires large headlands. Present field wagons need better flotation, their current turning radiuses tend to keep the wagons short so it is difficult to synchronize their movement with a harvester, and their payloads are low. Trucks are limited to an adequate traction condition. Grab loaders cannot be improved and probably they should be eliminated. Continuous loaders should be eliminated, but if kept, they probably could be improved with better design. Field wagons should be made longer and flotation increased. Trucks should be more compatible with field wagons to cut down inefficiencies. For haul and unload, either the material can be moved in batches as is currently being done or possibly some continuous method of movement could be developed.

Based on these answers, the original questions were replaced with the following:

1. How can field wagons be made longer and flotation increased?

2. How can trucks be made more compatible with field wagons so inefficiencies are reduced?

When examining these questions,

it was concluded that they could not be partially answered. Thus the hierarchy had been fully developed and contained 44 lowest level questions, which if answered would provide information needed to improve current harvesting methods.

Activity 3—Set Priorities on Questions

Available resources were not adequate to research all 44 questions. Little political or adoption restraints could be identified that would govern setting priorities on the research questions. The primary criteria appeared to be urgency in obtaining answers and probability of success. Based on these criteria, the priority for the five major independent questions under question III was determined to be B, C, D, A, E.

Several considerations have bearing on the priorities of the subquestions under B. Question 1 is an agronomic approach, which may require several years to answer, and the other three are mechanical, which might be answered more quickly. Some research has been done on question 4 to indicate that capacity will be a problem with this solution. Answers to the mechanical questions would lead to a flexible solution, since it should be relatively easy to incorporate mechanisms into a machine. Furthermore, research facilities to answer the questions would also be applicable to similar approaches under questions C and D, where feasible agronomic approaches do not appear to exist. Thus the priority for the questions under B was established as 3, 2, 4, and 1.

Considerations in establishing priority of the subquestions under question C included the fact that burning appears to have many problems that include safety, pollution, and expense. Cleaning rolls have a limited capacity as was noted earlier. Consequently, the priorities were established on the subquestions as 2, 3, and 1.

When considering priorities of the subquestions under question D, the suspension velocities for foreign matter should be determined in conjunction with any top and leaf trash experiments. Any harvesting machine will need conveyors, and the amount of material when cut from the row may need to be broken up. Consequently, the priorities were set on the three subquestions as 2, 1, and 3.

When establishing priorities on the subquestions under question A, no strong reasons could be determined that would indicate a clear urgency of one over another. Subquestions 1 and 2 appear to be about of equal priority but slightly higher than subquestion 3. In a similar manner, the priorities of the subquestions under question E appear to be about equal.

Activity 4—Allocate Resources to Highest Priority Questions

An examination of the priorities established on the hierarchy of questions indicates that they could be grouped into two research projects. The first was facilities and experiments that would determine suspension and conveying velocities (questions III.B.3, III.C.2, and III.D.1). The second was research on a spike-tooth cleaner conveyor (question III.D.2). Because all the research effort was being done at one geographic location, allocation became simply deciding the amount of effort to devote to each project. That decision could be made by the scientists at the location as they attempted to optimize their productivity within the limitations of their time and available resources.

Summary

The example presented is relatively simple because the identified area was small. Thus activities 1, 3,

and 4 were simple to carry out. But even for the relatively simple example presented, considerable effort was required in activity 2 to develop a hierarchy of questions. However, a balance between control from the top and freedom at the bottom requires developing and accepting a hierarchy of questions as the basic planning structure. If research scientists participate in the development, particularly the lowest level questions, and in setting of priorities, they will accept the questions as research objective and thus have guidance on what to research. But this guidance in itself will cause few restrictions on how to go about the research. Obviously available resources can greatly influence how scientists can proceed, but their scientific integrity and creativity are not prescribed. Thus they will have the primary freedom they desire.

On the other hand, management's involvement in establishing the hierarchy and the priorities lets management guide research efforts into what is considered to be the most justifiable areas so that it has a suitable degree of control. For example, an answer to question I in the example presented, though a possible solution, involves much more policy setting and possibly education than research. Thus having a harvesting research group struggling with the issues involved is not a very wise use of expertise. If that solution should be pursued, a different group of people should be involved. Similarly an answer to question II could provide a viable solution and obtaining it primarily involves research, but a different group of research scientists likely would be more effective. Thus if top "management" (research managers, sugarcane processors, or sugarcane producers) considered that research in that area was justified, it could have initiated additional planning in that area and established a different group of scientists to do the research.

Developing a hierarchy of questions that need answering is an essential activity of the systematic procedures for planning research. The hierarchy provides the linkage or structure between broad alternative solutions - the questions at the top and the small sharp researchable questions at the bottom. The lowest level questions provide guidance to scientists on what should be researched without unduly restricting their freedom on how to go about the research. To the degree that joint participation has taken place at the appropriate times in the planning efforts, commitment to and support of the plans will occur and that will achieve the desired control from the top with freedom at the bottom.

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